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MARCH 2021

Eos

SCIENCE NEWS BY AGU

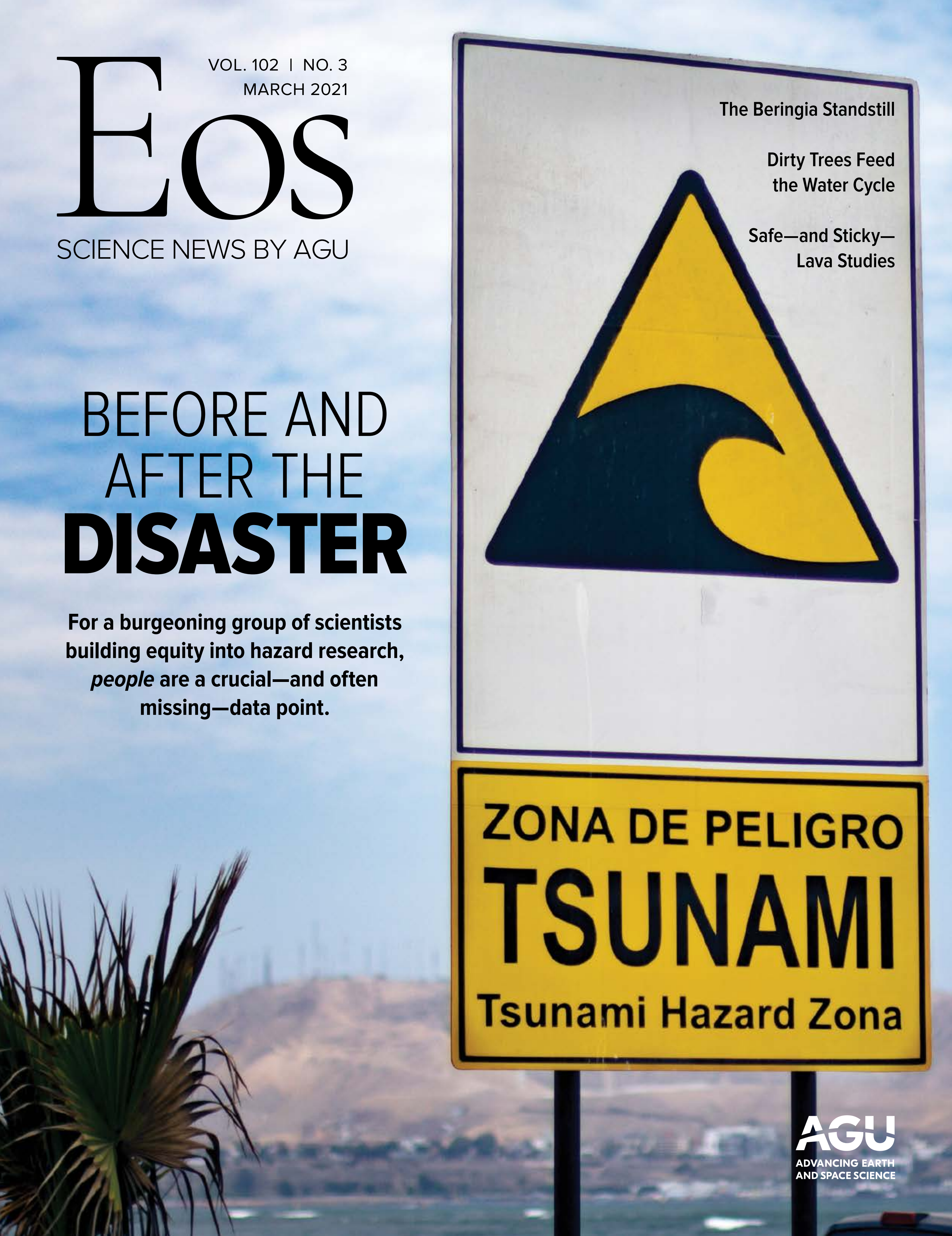
The Beringia Standstill

Dirty Trees Feed the Water Cycle

Safe—and Sticky—Lava Studies

BEFORE AND AFTER THE **DISASTER**

For a burgeoning group of scientists building equity into hazard research, *people* are a crucial—and often missing—data point.



AGU
ADVANCING EARTH AND SPACE SCIENCE

Building Equity into Hazard Research

"There is growing recognition that the effects of natural hazards are unequally distributed across the population and that certain communities face greater challenges in accessing resources to prepare for, respond to, and recover from disasters," said Michelle Hummel, an assistant professor at the University of Texas at Arlington and the *Eos* Science Adviser from AGU's Natural Hazards section. Hummel proposed the idea for our March issue theme on increasing equity in the way we deal with hazards and disasters.

We reached out to scientists across a spectrum of fields who are all working toward the same goal. Alessandra Jerolleman writes on page 21 about the need to better understand how disasters hit rural areas. These communities often have outdated building and zoning codes and face administrative challenges in applying for aid but can also be exceptionally adaptable because of a strong sense of self-reliance. On the whole, policymakers just don't have enough social science research to incorporate with geohazard data to better assist these areas. Jerolleman offers several approaches for scientists and local leaders to follow.

Eric Tate and Christopher Emrich are providing a great example of just this kind of approach. On page 24 they discuss their work incorporating social vulnerability assessments into hazard models. They aim to inform better mitigation planning as well as recovery programs. Our reporting on that intersection of science and policy in "Natural Hazards Have Unnatural Impacts—What More Can Science Do?" on page 36 also looks at better mitigation efforts.

"I was really encouraged to learn about FEMA's Building Resilient Infrastructure and Communities program, which focuses on predisaster mitigation and incentivizes projects that account for social vulnerability and future climate change," said Hummel. "This is a great example of how scientists and policymakers can come together to pass forward-looking legislation that helps communities prepare for future hazards."

Finally, we take a look at the Global Earthquake Model Foundation in Italy on page 30. The group's mission is to make the world more resilient to earthquakes, and a crucial part of that is incorporating the human element into their model. Read more about their enormous undertaking to collect information on population locations, economic compositions, building density, and zoning codes around the world—and then put every last bit into a simulation to shake around.

I'd like to thank Tiegan Hobbs and Leah Salditch, who are leading a new Hazards Equity Working Group at AGU. "The group focuses on how science can be used to help communities and policymakers address the need for equity in natural disaster mitigation," said Hummel. "It also explores ways by which its efforts may help in fostering participation and inclusion of underrepresented groups in natural hazards science and increasing the diversity of the natural hazards community."

Hobbs and Salditch, along with Hummel, directed us to many of the scientists doing important work in this area who are featured in this issue. We're proud to highlight their work and look forward to seeing how this movement grows.

Heather Goss, Editor in Chief

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Randy Fiser, Executive Director/CEO

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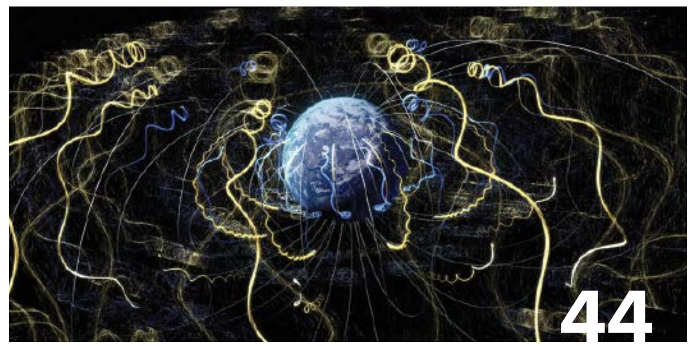
Features

On the Cover

A sign near the ocean in Lima, Peru, warns of danger in a tsunami hazard zone. Credit: ©Morganeborzee/Dreamstime.com



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Prince Sultan Bin Abdulaziz International Prize for Water

Recognizing Innovation

Winners for the 9th Award (2020)

Creativity Prize

Creativity Prize


Dr. Benjamin S. Hsiao

1) The team of Dr. Benjamin S. Hsiao (Stony Brook University, New York, USA)
for the development of adsorbents, coagulants and membrane materials from sustainable, biomass-sourced nanocellulose fibres along with numerous practical applications that promise to provide effective water purification for off-grid communities of the developing world. (The team also includes Dr. Priyanka Sharma, research scientist at Stony Brook University).


Dr. Sherif El-Safty

2) The team of Dr. Sherif El-Safty (National Institute for Materials Science, Japan)
for developing novel nano-materials in hierarchal and micrometric monoliths to achieve a nano-filtration/capture/detection process that quantitatively detects and selectively removes a wide range of water contaminants in a single step. A diverse range of these materials, which are conducive to mass-scale production, provides nano-filtration membranes and filters for water management applications, including purification, remediation, and the monitoring of hazard levels of various water sources.

Surface Water Prize

Surface Water Prize


Dr. Zbigniew Kundzewicz

Dr. Zbigniew Kundzewicz (Polish Academy of Sciences, Poznan)
for advancing our understanding of the relationship between flood risk, river flow, and climate change.

Groundwater Prize

Groundwater Prize


Dr. J. Jaime Gómez-Hernández

Dr. J. Jaime Gómez-Hernández (Universitat Politècnica de València, Spain)
for pioneering work on solving the "inverse problem" in hydrogeology.

Alternative Water Resources Prize

Alternative Water Resources Prize


Dr. Peng Wang

Dr. Peng Wang (King Abdullah University of Science and Technology, Thuwal, Saudi Arabia)
for work at the forefront of solar-evaporation water production technology.

Water Management and Protection Prize

Water Management & Protection Prize


Dr. Jay R. Lund

Dr. Jay R. Lund (University of California Davis, USA)
for the development of the CALVIN water supply optimization model that couples traditional water-supply criteria with economic considerations.

Nominations are open for the 10th Award. Nominations can be made online until 31 December 2021.

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Overturning in the Pacific May Have Enabled a "Standstill" in Beringia

The forbidding Bering Strait, which today separates Asia (left) and North America, may once have had a warmer climate that allowed for settlement. Credit: SeaWiFS Project, NASA/Goddard Space Flight Center, and ORBIMAGE

Planet Earth pulled out all the stops, it seems, to enable the first humans to reach North America. When a glacial period lowered sea levels and turned parts of the Bering Strait into a land bridge, a warm ocean current shielded that region from the worst cold, turning it into a refuge where ancestors of the first Americans found shelter for thousands of years.

Evidence of that current, which doesn't exist today, was published recently in *Science Advances* (bit.ly/Pacific-overturning).

That there was a "Beringian Standstill" in the trek between the continents is suggested by DNA differences between Native Americans and Asians. These differences suggest that it's been about 25,000 years since the two populations diverged. But scientists know that humans likely spread out across the Americas only about 15,000 years ago.

One possible explanation for this discrepancy is that the migration from Asia to the Americas stalled in Beringia, a region now submerged by the Bering Sea. The new study, led by James Rae of the University of St Andrews in the United Kingdom, suggests why ancient migrants may have found Beringia an attractive place to settle. "Rather than being this harsher version of modern Kamchatka and Siberia, it might actually have been more like Scotland," Rae said.

Proposing a PMOC

Rae's analysis of sediment cores and climate model calculations suggests that during the Last Glacial Maximum (LGM), a Pacific meridional overturning circulation (PMOC) pattern was active. The proposed PMOC functioned much like the Atlantic version, the AMOC, which today gives western Europe its temperate climate. The AMOC is driven by cold and salty, and hence dense, water sinking near the Arctic, pulling in warm surface water from the south while itself streaming southward below the surface currents.

Oceanographers have wondered why today there isn't such a conveyor belt for heat in the North Pacific. In fact, even today's climate models sometimes switch Earth into a mode where there's a PMOC instead of an AMOC. In such cases, models are normally nudged to represent Earth as we know it by increasing the net amount of fresh water the Pacific receives as rain, thanks to water vapor being blown west across the isthmus of Panama. This phenomenon makes Pacific water less salty and thus less dense.

For his study, Rae did the reverse in a number of different climate models, until a PMOC arose. He compared the results with what was known about past conditions in the ocean, culled from sediment cores containing the remains of tiny shelled organisms called foraminifera.

Such cores are relatively hard to come by because the Pacific is "not surrounded by as many oceanographic institutes as the North Atlantic," Rae said. The Pacific is also deeper and more acidic—and both pressure and acidity promote the dissolving of the carbonate shells of foraminifera. "Most of the ocean floor is just red clay, barren of any foram shells," Rae said.

Rae thinks his results confirm the existence of a PMOC. Running the climate models with a PMOC showed that the ocean's surface layer would become depleted in nutrients because it would consist of water from the subtropics, where year-round stratification and unfavorable wind stress restrict nutrient supply from below. And indeed, cores taken from shallower depths, from the Asian and American continental slopes and from the flanks of seamounts, had so far shown that during the LGM the surface water of the North Pacific contained fewer nutrients than it does today.

Beringian Standstill and Human Migration

Rae happened to read an article about the Beringian Standstill in *Science* (bit.ly/Beringian-standstill) and applied his results to the concept. "I became aware of this idea that people may have lived in Beringia in the peak of the last Ice Age. And there is some indication from pollen and things like fossil beetles that the climate there might have been surprisingly mild," he said.

Rae's models showed that the PMOC would have given Beringia a regional climate that was vastly more welcoming than anything to the east or west. Conditions were even milder than John Hoffecker, one of the authors of the *Science* article and a researcher at the University of Colorado Boulder, expected.

Hoffecker cautioned, however, that although Rae's results support the idea of a northern refugium for people in Beringia, it doesn't clinch the case. "We still can't confirm that people were actually present in Beringia during the LGM," he said. "And, even if we can eventually confirm a human presence, we will have to confirm that they represented the Native American founder population."

By **Bas den Hond** (bas@stellarstories.com), Science Writer

Modeling the Creation of Cratons, Earth's Secret Keepers

The continents, the solid blocks of land beneath our feet, weren't always as strong as they've come to be. Scientists from Monash University in Australia have devised a new mechanism to explain how the roots of the continents—cratons—came to be. Using numerical models to simulate the conditions of Archean era Earth, the researchers' findings, published in *Nature,* show that a strong base for the continents emerged from the melting and stretching of the cratonic lithospheric mantle (bit.ly/cratonic-mantle).

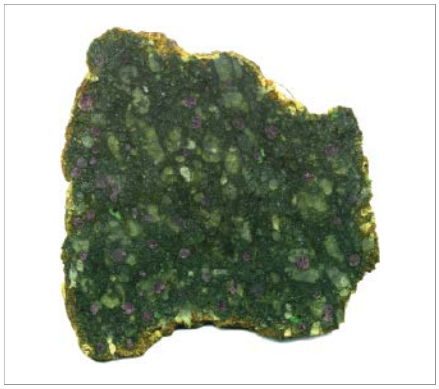
Cratons form the base of continents and hold the title of the oldest existing portion of the lithosphere. They're extremely thick and began to form up to 3 billion years ago, in the Archean eon. "They're the secret keepers of the Earth," said Catherine Cooper, an associate professor of geophysics in the School of the Environment at Washington State University in Pullman. Cooper was not involved in the new research. By studying cratons, scientists might learn how major components of Earth arose and how plate tectonics began. "If you can understand the role of the secret keepers within [Earth], then we can try to answer some of those questions better," she said.

Scientists can also use this knowledge to study other planets. "Because these processes are the creators of the continents, they are also the processes that create topography, that create an atmosphere," said Fabio Capitanio, lead author of the new study and an Australian Research Council Future Fellow in Monash University's School of Earth Atmosphere and Environment. "In principle, they are related to the way we understand life [and the] evolution of planets."

"How do we create long-lived, stable features out of material that was once deformable?"

The Craton Conundrum

The fact that cratons are so thick and enduring poses a problem for scientists. "To make really thick lithosphere requires a good deal of deformation," said Cooper. "How do we create long-lived, stable features out of material that was once deformable?"



By studying peridotite xenoliths (like this garnet lherzolite) that come from cratonic lithospheric mantle, scientists can see what conditions may have formed cratons. Credit: James St. John, CC-BY-2.0 (bit.ly/ccby2-0)

To figure this out, Capitanio and his colleagues turned to numerical models. To simulate the dynamics of the Archean lithosphere, the researchers modeled these layers' estimated temperatures, pressure, convection, and viscosity, all variables involved in melting rock.

A Surprising Solution

The model revealed a counterintuitive story for craton formation: Parts of the lithospheric mantle became stronger as parts of it were extracted. "The part that is extracted [from the mantle] is essentially melt," Capitanio said. "Imagine a volcano taking out the lava from the interior of the Earth." That melt came up through the lithospheric mantle, where it cooled to form crust, leaving behind a portion of mantle devoid of fluids. This process, called dehydration stiffening, left behind a thicker, stronger, and cooling mantle embedded in the lithosphere, forming the roots of the continents.

This residual mantle acts almost like a pin from which the lithosphere stretches laterally, creating new spaces for deformation (melting) and a new zone of stretching. This stretching, or rifting, brings the warmer, deeper material closer to the surface. "In doing so, then you're having higher temperatures at lower pressures, which then can cause [further] melting to occur," said Cooper. While the residual portion of the mantle cools, the whole process—dehydration stiffening, rifting, and cooling—repeats in a new section.

"This is a very nice study that unifies many parts of the complicated story of craton formation," said Lijun Liu, a geodynamicist at the University of Illinois at Urbana-Champaign not involved in the research. "Because it's a numerical model, it comprehensively brings together many parts [of craton formation] that were hard to reconcile previously." But, he added, this mechanism doesn't explain the entire story of cratonic origins.

"It sets the stage for the right material," said Cooper. But scientists know that cratons are extremely thick, and she said that this mechanism doesn't fully explain how that happened. "This is a great way to form the material that needs to be thickened later, or further thickened," said Cooper.

This mechanism aligns with observations of modern cratons. By studying the composition of xenoliths containing pieces of the Archean cratonic lithosphere (brought to Earth's surface through volcanic activity), scientists can learn about the composition of cratons. The composition also suggests what kinds of conditions might have existed to form that rock, and Capitanio's mechanism accounts for the pressure and temperature conditions that scientists know are needed to form the material of the Archean cratonic lithosphere.

"[Cratons] have kind of gone along for the ride, picking up all of Earth's secrets for all this time," said Cooper. "They're such an intriguing scientific story."

As scientists gain a firmer grasp of the origins of cratons, they're better able to understand processes that might be happening within other planets as well as the processes that helped form our own. "[Cratons] have kind of gone along for the ride, picking up all of Earth's secrets for all this time," said Cooper. "They're such an intriguing scientific story."

By **Jackie Rocheleau** (@JackieRocheleau), Science Writer

European Colonists Dramatically Increased North American Erosion Rates

Everything wears away in time, but human activities like farming can dramatically accelerate natural erosion rates. The arrival of European colonists in North America, for instance, sped up the rate of erosion and river sediment accumulation on the continent by a factor of 10, according to a new study.

An international team of researchers from China, Belgium, and the United States analyzed 40,000 years of accumulated river sediment from sites across North America to determine the natural background rate of erosion on the continent. They compared this rate to that of the past 200 years, a time when both agriculture and population rapidly increased following European colonization. During the past century alone, humans moved as much material as would be moved by natural processes in 700–3,000 years, the team reported in *Nature Communications* (bit.ly/humans-erosion).

"By having this huge compilation [of data] that stretches back many thousands of years, we're able to contextualize the human impact against that natural geologic variability," said lead author David Kemp, a geologist with the China University of Geosciences in Wuhan. "It was a surprise to me that the jump was there and that it seemed to be so neatly coincident with European arrival."

The development of large-scale agricultural systems (like this field in New Orleans) likely contributed to skyrocketing erosion rates in North America over the past 200 years. Credit: Veerle Vanacker

A Widespread Trend

To reach their findings, the team compiled data on sediment accumulated in riverbeds from 126 sites across the United States and Canada. In 94% of the sites surveyed, sediment accumulation rates over the past 200 years were faster than the expected geological rate. Even more dramatic, nearly 40% had a rate of sediment accumulation at least 10 times that of the background rate.

"What I found particularly interesting in the results is that if you look at human impact on the sedimentation rate, you see it continent-wide," said study coauthor Veerle Vanacker, a geomorphologist at Université Catholique de Louvain in Louvain-la-Neuve, Belgium. "I think that's quite important, because it shows that this is something which has been generalized over the entire area."

The researchers cite intensive farming as the likely culprit in the increased sediment accumulation rate, with forestry, ranching, and river management also playing roles. Sediment accumulation rates shot up around the turn of the 19th century, a time period that coincides with a sharp increase in both the European population in North America and the amount of land dedicated to agriculture. Prior to that time, humans did not have a noticeable impact on erosion rates in North America.

Accounting for the Sadler Effect

To compare the background rate of accumulation over 40,000 years with accumulation rates over more recent timescales, the team had to account for a known complication called the Sadler effect, named after study coauthor Peter Sadler of the University of California, Riverside. According to the Sadler effect, the farther back in time you go, the slower the erosion rate appears to be. More fine scale changes can be smoothed away or eroded over time, and layers can be lost altogether.

"With this effect in mind, you can see how a recent increase in sediment accumulation compared to the past 40,000 years may simply be the result of this time bias," said Gary Stinchcomb, a soil geomorphologist at Murray State University in Murray, Ky., who was not involved in the study. "I think the most exciting find of this study is that they addressed the time span dependence problem and still found [that] humans affected sediment accumulation" going back 200 years.

Informing Restoration Efforts

According to the researchers, their findings can help inform modern soil and water conservation efforts by providing a benchmark for natural erosion rates. "There are large and costly river valley restoration projects under way all over North America," Stinchcomb said. "One could argue that the work presented in [this study] shows us that we will need to peer back before 200 years ago if we want to restore these streams to a more 'natural' condition."

The most recent data in the study also provide a glimpse at whether ongoing restoration efforts have worked. "There have been huge investments in soil and water conservation techniques, and one of the questions is always the effectiveness of these techniques," Vanacker said. "I think that the results show these programs can probably be very effective, because you see that during the last decades, there already seems to be a reduction of the sedimentation rates."

By **Rachel Fritts** (@rachel_fritts), Science Writer

To Make Better Hurricane Models, Consider Air Pollution

Hurricane Harvey shocked the world in 2017 when it stalled over Houston, defying hurricane models and dumping 1.25 meters of rain onto the city. According to new research by a team of atmospheric scientists, a previously unaccounted for variable helped to drive the deluge: industrial air pollution.

To investigate the role of air pollution, the researchers compared models with and without aerosols to observed data on Hurricane Harvey's path, rainfall, and lightning extent. They found that air pollution was the major factor that drove catastrophic flooding in Houston, concluding that National Weather Service models failed to predict the rainfall because they didn't take industrial aerosols into account. They reported their findings in *Geophysical Research Letters* (bit.ly/Harvey-aerosols).

"The study presents compelling evidence illustrating the widespread effects of industrial aerosols on the evolution of Hurricane Harvey," said Zhanqing Li, an atmospheric scientist who specializes in aerosols and was not involved in the study.

Hurricane Harvey churns over the Gulf of Mexico in 2017. Credit: NASA

The Striking Impact of Aerosols

In recent years, researchers have begun to scrutinize the relationship between air pollution and storms. Wildfires' combined smoke and heat can affect local weather, for instance, and lightning is more frequent over polluted skies.

Particulate matter, especially very fine soot, can hover in the air for extended periods of time before settling to the ground, providing a focal point around which water molecules can condense. When water droplets form around the particles, a small amount of heat is released. In this way, more pollution leads to more condensed water and more heat, which in turn produces heavier rainfall and more intense lightning.

Conditions in Houston came together to maximize aerosols' amplifying effects during Hurricane Harvey. Southern Texas has more than 400 densely distributed oil refineries, and Houston in particular often exceeds national average annual air pollution levels.

But although previous studies have tried to understand how the urban heat island effect and global warming affected Hurricane Harvey, no one had yet focused their attention on the role of the city's air pollution. "I think we are among the first to argue that the aerosols played a determinant role in producing the large amount of precipitation," said Yuan Wang, an atmospheric scientist at the California Institute of Technology in Pasadena and a coauthor of the study.

Hurricane Harvey's Perfect Storm

During the time that Hurricane Harvey sat over Houston, a continuous source of moisture was coming in from the Gulf of Mexico. On top of that already hefty source of rain, factories continued to spew out more aerosols, providing a continuous source of air particles to supercharge the storm.

"In this case, all the factors came together to set the stage for aerosols to play a huge role," Wang said.

To test the idea that Houston's air pollution played a role in Hurricane Harvey's record-smashing rainfall, the researchers looked at both ground- and satellite-based rain and lightning measurements to get a clear understanding of the actual amount of rainfall and lightning over Houston between 26 and 28 August 2017. They then used the cloud-resolving Weather Research and Forecasting model to simulate Hurricane Harvey with and without the presence of Houston's industrial air pollution.

The simulation incorporating air pollution data accurately modeled Hurricane Harvey's actual rainfall rate of 32 millimeters per hour and also predicted the particularly intense lightning observed during the hurricane. The "clean" simulation, in contrast, predicted less than half that rate of rainfall.

The "clean" simulation, in contrast, predicted less than half that rate of rainfall.

The team's findings show that greenhouse gas emissions can have profound impacts on extreme weather events at even the local level, Wang said. Failing to take these impacts seriously can have serious consequences and heavy costs.

"Traditionally, in the hurricane community, aerosol effects have always been neglected in operational forecast models," Li said. "This work shows that such an omission may lead to significant errors in hurricane forecast and predictions."

By **Rachel Fritts** (@rachel_fritts), Science Writer

Corn Syrup Reveals How Bubbles Affect Lava's Flow

Hawaii's Kīlauea volcano erupting in 2018. Credit: U.S. Geological Survey

In the summer of 2018, an eruption on the flanks of the active volcano Kīlauea in Hawaii sent lava flowing through the Puna district toward Kapoho Bay. The relentless threat from wide channels of molten rock forced about 2,000 residents to evacuate. By the end of the eruption in early September, 24 people were injured, 716 structures were destroyed, and the flows left $800 million worth of damage in their wake.

Although it's not uncommon for lava flows to have bubbles, samples from the 2018 Kīlauea event revealed a high percentage of gaseous bubbles by volume—more than 50% in some cores taken after the flows solidified, according to research presented at AGU's Fall Meeting 2020 (bit.ly/bubbly-lava). Some of the bubbles were large, roughly a meter in diameter. The high-profile event provided an opportunity for volcanologists to observe up close how dramatic outgassing affected the way lava flows down slopes and spreads across flatter areas.

However, re-creating a stream of molten rock in the lab to capture detailed physics in action isn't feasible. So a team of international scientists created an analogue using corn syrup, baking soda, citric acid, and an inclined slope with the aim of shedding light on how a high volume of bubbles affects the way lava flows.

Atsuko Namiki, a volcanologist from Hiroshima University in Japan, was on Hawaii when the eruption occurred. She noticed that the flow was "amazingly quick" at first, but it became much slower as it continued away from the rift zone on the volcano's slopes.

"I was really surprised at the difference," said Namiki. "I wanted to explain the abrupt change of the flow patterns with bubbles and without bubbles."

"This has potential to be the basis for a lot of future research.

The researchers' findings showed that bubbles clearly affect lava's viscosity, or its relative thickness and fluidity. "Small changes in texture can lead to big and lasting changes in dynamics," said Janine Birnbaum, a graduate student at the Lamont-Doherty Earth Observatory at Columbia University who worked on the study.

Corn syrup is a common experimental analogue for lava. According to Birnbaum, the syrup's viscosity can be tweaked by researchers, which makes it ideal to work with. In this experiment, researchers created three liquids using corn syrup and differing infusions of citric acid: pure corn syrup with no bubbles, bubbly corn syrup, and bubbly corn syrup containing suspended particles.

The researchers then poured the liquids down a meter-long plastic plank propped up at an acute angle to mimic how lava flows from a volcano. A camera tracked movement while a laser sensor monitored the bubbly flows' thickness.

Pure corn syrup containing no bubbles moved the fastest, with bubbly corn syrup flowing slightly less rapidly. Bubbly corn syrup suffused with particulate matter moved more slowly and split into channels that flowed at different speeds—the liquid in the middle section moved faster, whereas the liquid on the flow's flanks moved more slowly.

The experiment also revealed a gravitational separation occurring, with bubbles floating to the top as the fluid moved—a process that creates a fragile gaseous shell in lava called pahoehoe in real flows. As bubbles rose to the top, the flow's more concentrated liquid touched the base of the slope, where it accelerated the flow's overall speed.

According to Pranabendu Moitra, a physical volcanologist at the University of Arizona who was not involved in the study, the research represents an effort to understand lava flow in all three of its phases: liquid, bubbly, and particulate.

"This is one of the first of its kind," Moitra said. "This has potential to be the basis for a lot of future research."

Future lab experiments analyzing the detailed physics of lava flows could help provide more accurate predictions for communities at risk of damage from volcanic eruptions, said Birnbaum. Observations of a flow's likely movement patterns and speeds, depending on its gas content, could aid public safety authorities in preparing more reliable evacuation notices.

Not all results require expensive gear or trips to dangerous zones, said Namiki. She hopes the simplicity of their experiments, which used common and inexpensive materials, inspires others to continue similar research.

By **Allison Gasparini** (@astrogasparini), Science Writer

Waterways Change as Nearby Cities Grow

Large rivers powerfully sculpt landscapes, but their smaller brethren—streams—are much more numerous and affect local communities and ecosystems. Now scientists have used multidecadal data sets to trace how streamflow across the continental United States has changed in response to urbanization. They found a variety of trends, complicating the long-standing notion that city growth has a consistent impact on nearby waterways.

Researchers are studying how streams, like this one in Iowa, are affected by nearby urbanization, a new longitudinal study reveals. Credit: iStock.com/lynngrae

Decades of Streamflow

Aditi Bhaskar, a hydrologist at Colorado State University in Fort Collins, and her colleagues started by mining a U.S. Geological Survey (USGS) data set of streamflow measurements. The data set, which included measurements across the United States from more than 9,300 streamgages, stretches back decades. "That's our best national-scale measurement of streamflow," said Bhaskar.

Bhaskar and her collaborators combined these streamflow data with records of housing density and impervious surface cover (e.g., concrete, asphalt). They honed in on gages that had an uninterrupted streamflow record of at least 20 years and whose watersheds—ranging in size from 5 to 162 square kilometers—were undammed and also satisfied certain criteria related to size, impervious surface cover, and housing density.

"We wanted to look at watersheds while they're being urbanized," said Bhaskar.

The researchers whittled down their sample to 53 gages across the continental United States in areas such as Colorado Springs, Colo.; Indianapolis, Ind.; and Austin, Texas. The spatial coverage of the final sample is probably biased, Bhaskar and her colleagues noted. "Streamgages are largely put on perennial rivers, rivers that flow all year-round," said Bhaskar. "Our analysis is, of course, biased in the same way that the USGS streamgage network is biased."

Zooming In on City Growth

Bhaskar and her colleagues then matched each watershed with a similarly sized watershed that had experienced only minimal urbanization. That allowed the team to subtract climate-induced changes in streamflow and isolate just the changes associated with city growth.

The scientists found mixed results: Higher streamflows tended to exhibit increasing flows as areas urbanized, but lower streamflows experienced both increases and decreases in flow. "It was pretty evenly split between watersheds where low flows increased with urbanization and other watersheds where low flows decreased with urbanization," said Bhaskar. "We don't see consistency."

That's an important finding, said Sarah H. Ledford, a hydrologist at Georgia State University in Atlanta not involved in the research. It counters the assumption that streams everywhere exhibit a homogeneous response to urbanization. "Urban hydrology was oversimplified from the start," said Ledford.

Draw and Release

It makes sense that streamflow would vary as a city grows, said Bhaskar, because urban areas both draw and release water. "Upstream of the city, there's the withdrawal for the water supply. A little bit downstream, but upstream of the next city, is the wastewater effluent release."

Cities, with their impervious surfaces, also look different than nonurbanized areas. These surfaces prevent rainfall from filtering into the ground, so storm runoff, which is often routed directly to streams, can lead to increasingly high flows, said Bhaskar.

These results were published in *Water Resources Research* (bit.ly/streamflow-records).

Bhaskar and her colleagues are investigating a few individual watersheds in greater detail. The goal, she said, is to get a more nuanced look than what's possible with a national-scale study. In Maryland, the team is analyzing how the presence of green infrastructures—such as infiltration trenches and tree boxes—affects changes in streamflow. And in Colorado, they're looking at streamflow changes that result from a practice common in urban areas: watering one's lawn.

By **Katherine Kornei** (@KatherineKornei), Science Writer

Dirty Trees Shape Earth's Hydrologic and Carbon Cycles

When each raindrop falls through a forest canopy and reaches Earth, it ferries creatures and contaminants to soils and streams below. Researchers have only recently begun to explore the fine details of this journey; their work was featured in a session titled "Precipitation Partitioning by Vegetation" at AGU's virtual Fall Meeting 2020 (bit.ly/precip-partitioning).

As rain flows down grimy tree branches, it becomes a rich, nutritious tea for soil communities below. Credit: John Van Stan

When a raindrop falls over land, it might bounce off leaves or slide down tree trunks before reaching the ground. Depending on where it lands, that drop will eventually contribute to a river, be absorbed into a forest floor, or evaporate back into the atmosphere. This distribution of precipitation by trees and shrubs is often the first step in the terrestrial hydrologic cycle, yet fundamental data on its consequences remain relatively sparse.

"We tend to ignore canopies as an interface for water to reach the Earth's surface," said John Van Stan, an ecohydrologist at Georgia Southern University. "But they connect to so many aspects of an ecosystem. They're the first thing that controls where water goes."

More Questions Than Answers

When hydrologists consider what happens when rain filters through trees and plants, they confront a host of important ecological and societal questions: How much rainfall actually reaches an aquifer? How does clear-cutting a forest affect local weather? How do urban trees aid storm water management?

A growing set of research projects has focused on this botanical portion of the hydrologic cycle. These studies accompany the rise in popularity of critical zone science, which investigates the connectivity of the "thin living skin" that coats Earth—from treetops to bedrock. Measuring rain, fog, and snow within the convoluted texture of a forest, however, is no easy task.

"Because it's such a challenging measurement to take, [canopy water flow] has really been overlooked," said Ethan Gutmann, a hydrologist at the National Center for Atmospheric Research in Boulder, Colo. "But we're finding more and more, especially in water-limited environments, that it may be a very large component of the water cycle."

Last year, Van Stan, Gutmann, and their colleagues published a book that synthesizes past and present advances and ongoing knowledge gaps about the transport of water along the atmosphere-plant-soil continuum. The Fall Meeting session included a number of posters related to particulate transfer by precipitation and how human disturbances, such as forest thinning and fire, change the capacity for canopies to store water.

Gutmann said he's particularly excited about one study, led by Dominick Ciruzzi at the University of Wisconsin-Madison, in which a team attached accelerometers to street trees to measure how much rainfall they intercept on their leaves. The study showed that rainfall bound up in trees reduced the amount of water that reached the ground below. When taken together, thousands of trees in an urban area could be a sustainable tool to mitigate flooding related to heavy rains.

Miniature Amazons

According to Van Stan, one of the most understudied details of precipitation partitioning is the vertical transfer of biological materials from canopies to the soil below. "Trees are really dirty, just covered in lots of organic matter," such as feces, fungal spores, bacteria, and metazoans critical to how ecosystems function, Van Stan said.

The numerous, tiny rivulets that form on branches, trunks, and stems during storms are like miniature Amazons capable of transporting carbon and nutrients in volumes comparable to those of large streams and rivers. Yet "we know practically nothing about it," Van Stan said. Indeed, he noted, hydrologists interested in canopy water traditionally filtered out the organic matter and tossed it in the trash.

By directing water and nutrient flow within the critical zone, plants influence numerous biogeochemical cycles. But the extent of their influence remains a mystery.

"There are always modeling papers saying we still don't have the best handle on the carbon cycle," said Benjamin Runkle, who studies carbon and water cycling in agricultural systems at the University of Arkansas and was not involved in the session. Understanding the subtle yet powerful ways plants shape large-scale systems like weather, erosion, and carbon transport is critical to building better predictive models.

"To really get the numbers right," Runkle said, researchers need to pay more attention to the details, one drop—on one leaf—at a time.

By **Cypress Hansen** (@PollenPlankton), Science Writer

▶ Read our Critical Zone issue: eos.org/special-topics#critical-zone

New Volcano, Old Caldera

The island of Mayotte, Comoros, is the site of ongoing seismic activity associated with what may be the largest documented underwater volcanic eruption in history. Credit: Earth Science and Remote Sensing Unit, NASA Johnson Space Center

In May 2018, a barrage of earthquakes struck Mayotte, the seismically quiet easternmost island of the Comoros archipelago, which stretches between Africa and Madagascar. After months of investigating the unexpected and intense seismic activity, French scientists discovered a new submarine volcano in the Indian Ocean approximately 50 kilometers east of the island. This new seafloor feature is evidence of, by volume, the largest documented underwater volcanic eruption in history, and both volcanic and seismic activities continue today.

In the years since the initial quakes, teams of scientists have refined the picture of the structures below the seafloor. Building on this foundation, marine geologist Nathalie Feuillet and seismotectonicist Eric Jacques, both at the Institut de Physique du Globe de Paris, and their colleagues proposed the presence of a large underwater caldera—a volcanic depression formed when a magma chamber drains and collapses—located between Mayotte and the new volcano. A ring of earthquakes in the mantle lithosphere delineates this curious structure at depths where neither earthquakes nor calderas typically occur.

Feuillet, Jacques, and other researchers presented their findings at AGU's Fall Meeting 2020 (bit.ly/Mayotte-structure).

A Timeline of Peculiar Events

Mayotte formed approximately 11 million years ago and is the oldest in the chain of Comorian volcanic islands, said Feuillet. The island slumbered until 10 May 2018. Then, in the first 2 months of the seismic episode, more than 100 events greater than magnitude 4.5, including a magnitude 5.9 event, rocked the island. Its population, accustomed to stable ground, had only a single seismic station to monitor the sudden crisis.

In November 2018, seismic stations around the world heard a mysterious hum that scientists traced to Mayotte. This 25-minute-long signal vibrated at low frequencies, hinting that magma movement and volcanic activity were the prime suspects to explain the seismic crisis. Back at sea level, Feuillet said local fishermen reported dead fish and a "burned tire smell" during this time.

In May 2019, the first of seven marine cruises confirmed that 5 cubic kilometers of lava had piled onto the previously flat seafloor, constructing an 800-meter-tall volcanic edifice, said Feuillet in her talk. The presence of hydrogen gas in the water column meant that the nascent volcano was actively erupting into the sea during the scientific cruise. With each subsequent campaign, scientists discovered fresh lava flows.

From Seafloor to Mantle

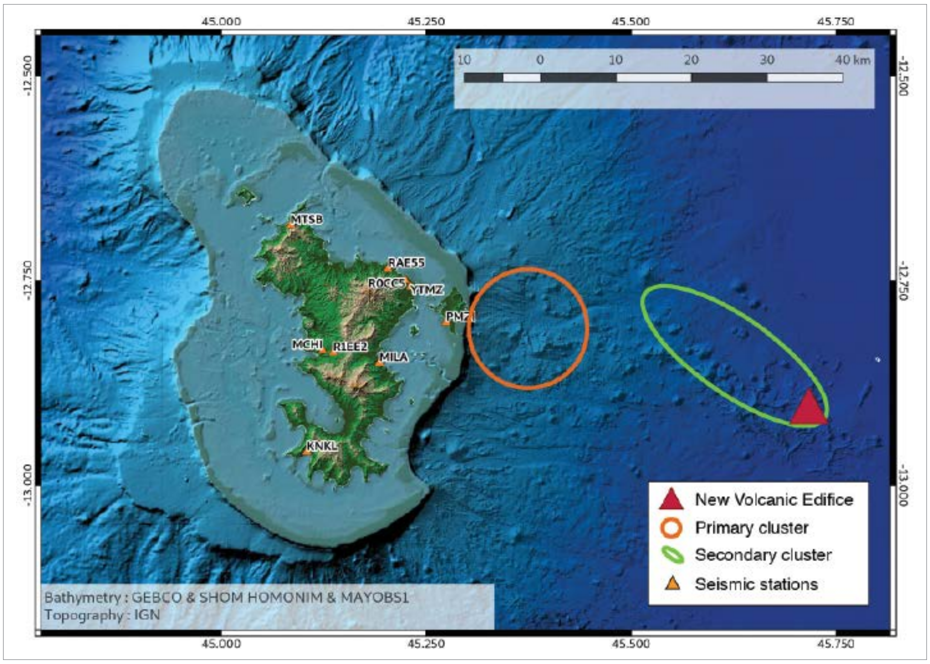
East of Mayotte's shores, Feuillet described "the crown," a circular structure on the seafloor approximately 10 kilometers in diameter and dotted with many cones. She and her colleagues interpreted the structure as the outline of an old caldera. An oceanic ridge stretches eastward, away from the crown, truncated by the fledgling volcano 50 kilometers from Mayotte.

To explore the structures in the lithosphere below the seafloor, the team focused on two distinct clusters of earthquakes. The eastern cluster, located between the suspected caldera and the volcano, concentrates earthquakes deep below the seafloor, parallel to the ridge, said Jacques. This cluster includes the inaugural earthquakes from May and June 2018, which Feuillet said may indicate that a dike propagated from west to east before the eruption, pushing magma from a deep western reservoir eastward and upward toward the volcano, similar to the model proposed in a paper published earlier this year (bit.ly/Mayotte-magma-drainage).

The donut-shaped western cluster began shaking in the summer of 2018. Earthquakes tell scientists where faults are active, so this ringlike cluster implies faults arrayed in a circle pointing to a possible caldera directly above. At depths of 25–55 kilometers, these earthquakes originated in the mantle below, said seismologist Wenyuan Fan, an assistant professor of geophysics at Scripps Institution of Oceanography, who is not affiliated with the new studies. Earthquakes usually rupture brittle crust, where strain energy can accumulate, he said. Strain cannot accumulate at typical mantle conditions, so most mantle tends to flow, inhibiting earthquakes.

"One way to [get mantle earthquakes] would be to bring down cooler materials that can host earthquakes," Fan said, which happens in subduction zones. But the Mayotte events are not related to subduction, leaving these mantle earthquakes a mystery.

How the western donut cluster connects to the eastern ridge cluster poses another quandary because they are not linked by earthquakes, said seismologist Lise Retailleau, also of Institut de Physique du Globe de Paris but not part of Feuillet's and Jacques's studies. Whether the lack of seismic connection between the clusters indicates aseismic



In this map of the topography and bathymetry of Mayotte, the red triangle indicates the location of the new volcanic edifice. The orange circle indicates the primary donut cluster of earthquakes below the possible caldera structure. The green ellipse encloses the secondary cluster parallel to the caldera ridge. Credit: Lise Retailleau; bathymetry from GEBCO, SHOM HOMONIM, and REVOSIMA MAYOBS1; topography from IGN

magma transfer or some deeper connection hidden from scientists, she said, "we don't really know."

Also perplexing are observations of the lithosphere between the proposed caldera and the donut cluster. Retailleau pointed out that the caldera shows no evidence of volcanic activity at the human timescale, even though most of the seismicity recorded since 2018 congregates below it. Even stranger, the upper crustal lithosphere between the surface and the top of the donut cluster lacks earthquakes that would indicate breaking, brittle crust. Instead, long-period and very long period seismic events associated with this eruption—events that often imply magma movement—occur just above the donut, said Retailleau. Feuillet said that these events might foreshadow another untapped shallow magma chamber above the brittle rocks defined by the donut cluster. If this magma chamber is active and continues its upward path, Retailleau said it could affect Mayotte and its population of more than a quarter million people.

By **Alka Tripathy-Lang** (@DrAlkaTrip), Science Writer

Long-Term Drought Harms Mental Health in Rural Communities

Public health experts increasingly recognize that adverse weather and climate conditions can have negative impacts on people's mental health as well as their physical health. Many emergency management organizations, for example, have established or expanded postdisaster services to include mental health assistance and support. However, little is understood about how mental health is affected by the duration of such conditions, especially when they last for months or years on end, as can happen with droughts.

For farmers and ranchers in rural New South Wales, Australia (above), drought is a regular part of life and can cause long-term harm to mental health. Credit: iStock.com/Capstoc

Past quantitative research has focused on linking characteristics of drought, such as the severity of dryness, with mental health outcomes, explained Tuyen Luong, a doctoral student at the University of Newcastle's Centre for Resources Health and Safety (CRHS) in New South Wales, Australia. "In our study, we focus on linking duration of drought…with the mental health of people to explore their mental response to drought over time."

Residents of remote and rural communities in southeastern Australia likely remember the Millennium Drought, which lasted from 1997 to 2010 and devastated ecosystems, economies, and lives across the region. From 2007 to 2013, scientists conducted a study of people living in those communities to explore potential drivers of poor mental health, including the prolonged drought.

Luong and her colleagues recently analyzed data from that study and found that the Millennium Drought did indeed have adverse mental health impacts on people living through it in remote and rural communities. Moreover, although some acute symptoms of poor mental health seemed to lessen after a few years of the drought, other symptoms became persistent or chronic.

Luong presented this research at AGU's Fall Meeting 2020 (bit.ly/drought-mental-health).

Learning to Cope

Climate change is worsening drought conditions around the world and shifting natural drought cycles out of sync with agricultural growing periods..

"Australia is particularly vulnerable to drought because we have such variable rainfall," explained Emma Austin, manager of CRHS and a co-investigator on this research project. "Rural communities are very vulnerable to drought because they rely on agriculture. And within rural communities there are certain groups that are more vulnerable," like adolescents and the aging population.

Moreover, the effects of drought on physical health, financial stability, and other stressors like water availability are different for people living in rural and remote communities compared with people in urban settings. The results of drought–mental health studies that focus only on urban settings likely won't be applicable in rural and remote contexts, Austin said.

The Australian Rural Mental Health Study (ARMHS) repeatedly surveyed more than 1,800 households in remote and rural communities in New South Wales. Over a 6-year

Fields affected by the Millennium Drought, which lasted from 1997 to 2010 and severely affected farmers in southern and eastern Australia, are seen here near Benambra, Vic., in 2006. Credit: Fir0002/Wikimedia Commons, CC BY-NC 3.0 (bit.ly/ccbync3-0)

period, participants self-reported psychological symptoms of poor mental health like distress, worry, depression, anxiety, and suicidal thoughts, as well as the role of determinants in their mental health and well-being like employment stability, social connectedness, and environmental adversity.

In their analysis of these data, Luong and her team found that people's psychological distress rose during the first 30–40 months (roughly 2.5–3.5 years) of drought before plateauing and then decreasing.

"People have lower distress at the later stages of drought, but this does not necessarily mean that people will display a good mental health condition," Luong said. "We found that when droughts go on, [they] will lead to a reduction in general life satisfaction, and despair about the future will be increased."

Rather than indicating an improvement in overall mental health and well-being, Austin said, the alleviation of distress might be related to a developed trait known as adaptive capacity, a person's ability to cope with adversity.

"The finding that mental health decrements tend to dissipate over time but do not completely return to baseline within this time period makes a lot of sense, conceptually, especially if the drought is ongoing," said Susan Clayton, a professor of psychology and environmental studies at the College of Wooster in Wooster, Ohio. Clayton was not involved with this research. "People learn to cope, but the quality of life is still lower."

Informing Policies That Support Mental Health

"There's been a shift in Australian policy" in the past decade regarding drought, Austin said. "It was very reactive, [but] now there's focus on the need to plan for drought all the time, not just in the drought times but in the good times as well." Long-term, quantitative studies like ARMHS are needed to measure the true toll that adverse environmental conditions take on rural communities, she added.

"Research like this is important to share with governmental agencies in order to strengthen support for mental health treatment networks, as well as awareness of the problem," Clayton said. "Access to mental health treatment, especially in a way that is not stigmatized, can help people to cope with these kinds of negative effects. But it is often difficult to obtain, especially in rural areas. Even doctors focused on physical health, and other community officials, can be trained and encouraged to ask people about their mental health and refer them to treatment options as required."

Luong said that future analyses of ARMHS data will explore how gender, age, and income factor into drought-related mental health impacts. A more nuanced understanding of these factors can help create policies that provide the right kind of support through the entire period of mental health vulnerability and allocate often limited financial support to particularly at-risk populations.

"Our work will inform policy and strategy by providing better understanding" of the relationship among drought, mental health, and adaptive capacity, Luong said, "and from there we can develop strategies to improve well-being and therefore improve adaptive capacity and climate resilience in communities."

By **Kimberly M. S. Cartier** (@AstroKimCartier), Staff Writer

Tracing the Moisture That Nourishes the World's Highest Glacier

The Khumbu Glacier snakes down from the summit of Mount Everest and into northeastern Nepal. The highest glacier in the world, it's famous for being a treacherous rite of passage for Everest mountaineers. However, the Khumbu Glacier, along with others nearby, is also a key source of water for downstream communities in the Hindu Kush-Himalaya-Karakoram region.

Now, using newly installed weather stations on and around Mount Everest, scientists have determined that the Khumbu Glacier is largely nourished by moisture transported from the northern Bay of Bengal. Predicting whether this glacier will advance or retreat in the future might hinge on measurements of the Bay of Bengal's sea surface temperature, the scientists suggest, because warmer waters translate into a greater potential for evaporation.

A Far-Reaching Expedition

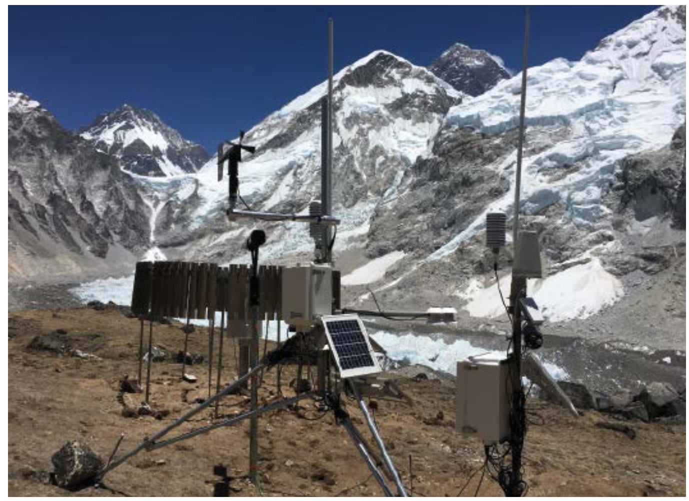
In 2019, 34 scientists and a cadre of support staff convened in Nepal for the National Geographic and Rolex Perpetual Planet Everest Expedition. Ten research teams—spanning biology, geology, glaciology, mapping, and meteorology—accomplished a number of firsts, including drilling the world's highest ice core and placing the two highest-elevation weather stations. (The logistics of supporting such an expedition were myriad: More than 2,900 kilograms of equipment and supplies had to be transported, by modes ranging from helicopter to dzo, a cow-yak hybrid.)

Baker Perry, a climate scientist at Appalachian State University in Boone, N.C., participated in the expedition. As colead of the meteorology team, he helped oversee the installation of five automatic weather stations on and around Mount Everest, including one just a few hundred meters below the mountain's 8,850-meter summit.

Working on the upper reaches of Mount Everest was a challenge even for Perry, who has spent time above 5,500 meters in the Andes mountains. "It was a new challenge getting up that high," he said. "It's just a different landscape."

Into the Void

But installing weather stations at high altitudes is extremely important, said Perry, because many glaciers are at elevation. If we want to better understand what controls a glacier's growth and retreat, we need to get a handle on the atmospheric conditions it's exposed to, he said. And right now, only a handful of weather stations are positioned above about 5,200 meters in the Himalayas. "There's this incredible data void up there," said Perry.



The Khumbu Glacier on Mount Everest is nourished by moisture from the northern Bay of Bengal, weather station data have revealed. Credit: Baker Perry/National Geographic

Perry and his colleagues have now analyzed data from several of the weather stations they installed. They extracted measurements like temperature, relative humidity, and wind speed and tabulated 171 precipitation events that occurred between 1 June 2019 and 31 May 2020 near the Khumbu Glacier. Precipitation can nourish glaciers by depositing snow that ultimately gets compacted into ice.

The researchers then used a computer model of how the atmosphere moves to trace each precipitation event backward in time and space. They found that more than 60% of the precipitation originated from the northern Bay of Bengal, with the remainder split roughly evenly between the Indo-Gangetic Plain and the Indus River Delta/Arabian Sea. That result is consistent with earlier results based on satellite data.

Watch the Temperature

These findings pinpoint the Bay of Bengal as an area to watch, said Perry. The amount of precipitation that ultimately falls in the accumulation zone of the Khumbu Glacier—a factor that dictates, in part, whether the glacier will advance or retreat—may be tied to the sea surface temperature in the Bay of Bengal, he said. "The warmer the sea surface temperatures there, the warmer the air, and the greater the potential for evaporation."

These results were published in *One Earth* and presented at AGU's Fall Meeting 2020 (bit.ly/Khumbu-moisture).

Perry and his colleagues aren't finished studying the Khumbu Glacier—they're particularly keen to understand how it will be affected by climate change. One hint comes from measurements of the freezing-level height on the glacier, the elevation at which precipitation ceases falling as rain and instead falls as snow. Freezing-level heights on the Khumbu Glacier have consistently crept upward by about 7 meters per year since 2005, Perry and his collaborators have shown.

That's a worrying trend, said Mauri Pelto, a glaciologist at Nichols College in Dudley, Mass., not involved in the research. A higher freezing height means that a glacier will receive a larger fraction of its precipitation in the form of rainfall, which will trigger melting, he said. "Snow adds to its mass, at least temporarily, whereas rain immediately generates melt."

There's another side effect of increased rainfall, Perry and his colleagues noted. By contributing an influx of water to lakes, it could potentially destabilize some of the many glacial lakes in the Hindu Kush-Himalaya-Karakoram region, said Perry. "This is a growing concern."

By **Katherine Kornei** (@KatherineKornei), Science Writer

Earth's Magnetic Field Holds Clues to Human History

The remains of mud brick walls like this one in Tel Batash, Israel, are helping researchers better understand the Levantine Iron Age geomagnetic anomaly, which lasted from the 10th to at least the 5th century BCE. Credit: Yoav Vaknin

Snapshots of the geomagnetic field sometimes can be linked to well-recorded events in history.

Destruction as a key to preserving the past? It sounds paradoxical—fires, floods, and war have often wiped out historic record https://aguorg-my.sharepoint.com/personal/vbassett_agu_org/_layouts/15/onedrive.aspx s and infrastructure. But destructive events are also a source of knowledge when it comes to the study of Earth's magnetic field. Items burned during ancient upheavals store geomagnetic information from long ago—and those data can illuminate the timeline of human history.

A research team specializing in archaeology and geomagnetism has collected magnetic information from burned mud bricks and other objects at 15 archaeological sites spread across the southern Levant. These efforts build on the team's recently published study that examines the direction and intensity of the geomagnetic field in 586 BCE, when Babylonian forces burned the city of Jerusalem (bit.ly/Jerusalem-magnetic-field). The new research is broader in scope than the paper is, providing detailed geomagnetic data from throughout the region during much of the Levantine Iron Age geomagnetic anomaly, a period of about 500–600 years when the intensity of the geomagnetic field was unusually high.

Yoav Vaknin, a Ph.D. student at Tel Aviv University and the Hebrew University of Jerusalem, presented the team's preliminarys results in a poster session at AGU's Fall Meeting 2020 (bit.ly/geomagnetic-anomaly).

"They're doing just really great work," said Michele Stillinger, a professor of Earth science at Dougherty Family College, University of St. Thomas, who was not involved in the research. "I'm excited to see what kind of results they get and to compare across the different sites."

Magnetic Memory

Many materials, including rocks and soils, contain minerals that are magnetic. When exposed to intense heat, the material's internal magnetic signature is erased. This happens to lava during a volcanic eruption, for example, and to clay pottery as it's fired in a kiln. As the material cools down again, it takes on the characteristics of the geomagnetic field that surrounds it.

Vaknin and his colleagues measured the magnetic direction and intensity of dried mud bricks, a common building material in the ancient Near East that was often burned during times of war. Although other objects (like pottery) are also viable sources of magnetic information, such items are less likely to remain fixed in place than blocks used in construction—and a shift in location and orientation makes it impossible to extract meaningful data on geomagnetic direction.

"A structure that has been fired in place in these destruction events gives you so much more data as to the exact moment in time when that destruction occurred," said Stillinger.

Multipurpose Time Capsule

Because the geomagnetic field is constantly changing direction and intensity, objects that burn at different times record different geomagnetic signatures. These snapshots of the geomagnetic field sometimes can be linked to well-recorded events in history—such as the destruction of Jerusalem. "We know [the city was burned] in August 586 BCE," said Vaknin. "There is an argument [over whether] it's 3 days earlier or 3 days later."

Such events are fundamental to archaeomagnetic dating, a process that first uses burned material to build a geomagnetic timeline, then uses that timeline to date other archaeological objects through their magnetic properties. This technique is an important complement to more traditional archaeological methods like radiocarbon dating. But Vaknin's data are also valuable for the study of geomagnetism itself.

All the magnetic information goes into a worldwide database, said Vaknin, and researchers try to reconstruct and build models of the behavior of the geomagnetic field. "It's a very big enigma, why the geomagnetic field behaves as it does."

By **Alice McBride** (alicemcb@mit.edu), Science Writer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How to Combat Bullying and Discrimination in the Geosciences

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Bullying and discrimination within the geosciences are widespread and affect the practice of science at individual, institutional, and societal levels, ultimately hampering scientific advancement [*Marín-Spiotta et al.*, 2020]. The majority of the perpetrators creating abusive research environments are supervisors [e.g., *Woolston*, 2019a, 2019b; *Iwasaki*, 2020]. Those most affected are early-career scientists from underrepresented groups [*Marín-Spiotta*, 2018; *Moss*, 2018]. As such, the lack of diversity in the geosciences [*Bernard and Cooperdock*, 2018] may give more opportunity for these injustices.

The root of this pervasive issue lies in the power dynamics within academia, where fears of retaliation and the impunity of professors let culprits get away with malicious behavior far too often. Despite increased discussions about this topic [e.g., *Nature*, 2019; *Smith*, 2020; *Wellcome Trust*, 2020], institutions, scientific organizations, and funders tend to provide neither effective support nor clear steps forward for those affected [*Iwasaki*, 2020; *Mahmoudi*, 2018]. Yet the onus of addressing hostile work climates should not be on the person experiencing abuse.

If you are witness to an unhealthy work environment involving bullying, discrimination, or other abuses of power (see sidebar), it is incumbent upon you to act as an ally to those experiencing abuse. Be mindful when talking with the person to make sure they are comfortable and supported while getting the help they need. If you are a peer of the hostile party, you could offer mentorship to help them change their behavior. You may want to elevate the matter to a higher authority—for instance, a department head or an institutional office that investigates reports of workplace abuse—for action to be taken. Above all, do not disregard or deny the victim's experience, blame them, or apologize for the perpetrator.

The onus of addressing hostile work climates should not be on the person experiencing abuse.

With or without vocal allies on their side, people experiencing abuse in academic environments can, and often must, be their own biggest advocates. We recommend 10 concrete strategies for scientists to overcome unhealthy work environments, particularly if support from their own institutions is lacking or ineffectual. Please note that these recommendations do not address ways to respond to sexual harassment or assault, stalking, threats, or other forms of physical violence.

1. Recognize an unhealthy work environment. Recognizing discriminatory behavior is the most crucial point, although the hierarchical nature of academia can make this recognition inherently difficult when it is someone you look up to who is misbehaving. First, if there is a problem, do not assume you are at fault! It is the responsibility of the person in power

to not be hostile in their actions or words. Academic institutions and departments should have definitions and guidelines for ethical behavior in place as well as policies protecting employees and students from harassment and bullying. Use these guidelines to assess your experiences, and keep a record of specific incidents to identify patterns. These measures can help you justify your perceptions and evaluate the situation. Needless to say, talk to family, friends, and other mentors for support and outside perspective.

2. Prioritize your well-being. Mental and physical well-being are inseparable and should be your first focus. Make sure you get enough sleep, take breaks, and do things that make you happy. You are valued for more than your capital and abilities as a scientist, and your well-being should never suffer. Do not hesitate to seek professional psychological help and other well-being resources and services, which many academic institutions already offer to their staff and students. There is no shame in getting external perspectives to guide you through your situation.

3. Confront your situation. It takes a lot of courage to approach a person who is harming you, particularly given the risks of their retaliation. However, by doing so, you take charge of the situation and signal to the culprit that their behavior is unacceptable. We recommend having such a discussion in a public place, for example, a cafeteria. If you feel more comfortable having a third party involved, reach out to a trusted person to join the conversation. Aim to establish agreements that detail how the perpetrator will change their behavior and how they will follow through with their role as a mentor in charge of your growth as a scientist.

4. Approach someone you trust. Reach out to a trusted individual for guidance. An ally who can effectively advise you and advocate for you can be an invaluable source of support and can help protect you from retaliation. Universities and research institutions often employ ombudspeople or others trained to mediate conflict situations. Seek guidance from these individuals, or, if your institution does not have staff trained in mediation, look for peer-mentoring support options at your institution and beyond—there are a myriad of early-career scientist networks, student councils, and online community resources of scientific societies, as well as Twitter and Slack groups.

5. Dare to speak up. It is possible or even likely that colleagues of yours face similar issues but have not spoken up. Finding the courage to do so can be hard for countless reasons. However, simply sharing experiences about and strategies on how to handle difficult work situations can already help you feel better. Sharing your experience with others could also create a "me too"-type effect, enabling you to act more effectively as a group against perpetrators. Moreover, having open conversations and removing taboos on discussions regarding harassment and bullying are important steps forward in acknowledging systemic problems.

6. Look for supportive collaborators. For most people, a hostile workplace will negatively affect the quality of their work. Try to find other experts in your field who can get involved in your research and act as mentors and allies. By expanding your team of supervisors or collaborators, you can diffuse the effects of power abuses that can occur in one-on-one relationships. Do not hesitate to approach potential collaborators with your scientific ideas at conferences or via email. However, make sure those scientists are not close associates or friends of the perpetrator. Widening your network of collaborators has the added benefit of creating relationships with people who may be able to provide letters of recommendation as you develop your career.

7. Change your physical work environment. Changing the physical environment in which you work can help put not only literal distance but also mental distance between you and an abusive situation. You could, for example, ask for a new work space in a different office, laboratory, or building; occasionally work from other places (e.g., the library or home); or look for opportunities to work as a visiting scientist in another research group. The latter can be facilitated by a travel grant (which also looks great on a CV) and can lead to relationships with new collaborators.

Changing the physical environment in which you work can help put not only literal distance but also mental distance between you and an abusive situation.

8. Document all incidents. Make notes and memos of important conversations with your supervisor and send them as meeting summaries. Such records can be key if your supervisor ignores agreements or your situation is elevated to an institutional level where "proof" of your situation is requested. Also, take note of bystanders who might have witnessed the discriminatory behavior you have experienced.

9. Transfer to another workplace or lab. Unfortunately, difficult and abusive situations do not always improve, even with the approaches outlined here. Staying in a hostile work environment can ruin your career, so your best option might be to move elsewhere to start fresh in a different research group, department, or even institution. Your happiness, mental health, and professional growth as a scientist are worth it!

10. Explore external resources. In addition to resources provided through your institution, professional societies and other groups provide external sources of support. For example, AGU has an Ethics and Equity Center that provides free legal consultation for those who may

What Are Bullying and Discrimination?

Bullying includes a range of aggressive and discrediting behavior carried out over a prolonged period. Discrimination refers to mistreatment, whether intended or not, on the basis of a person's belonging to a specific group or on account of disability; nationality; or social, ethnic, racial, sexual, gender, or religious identity. Bullying and discrimination typically lead to similar kinds of misconduct, which can occur in many forms, including the following:

- unfair and unequal working conditions, such as withholding information, collaboration opportunities, or support; assigning inappropriate or too many tasks; threats or refusals regarding funding; refusal of promotions; or discrimination because of pregnancy
- scientific misconduct, such as changing authorship positions or taking credit for other people's ideas or intellectual property
- intimidating behavior, such as constantly contradicting or interrupting someone
- attacks on personal integrity and dignity, such as spreading rumors or publicly shaming people
- psychological attacks, such as making degrading verbal or written comments or sexist or racist jokes

be targets of hostile and toxic environments. These resources and organizations can offer guidance on how to resolve conflict situations that potentially involve legal actions.

There is no straightforward or easy way to improve or get out of a discriminatory work environment. The above steps are intended to empower individuals facing abuse and to help overcome or alleviate the consequences of workplace bullying, discrimination, and other behaviors that stem from imbalanced power dynamics in academic settings. If you need distance to make a major decision, consider taking time off to clear your head. Whether you ultimately decide to stay in or leave a difficult situation, make sure to choose the option that is best for your well-being, and do not let the abuse you have experienced define how you value yourself personally or professionally.

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Building Resilience in Rural America

Shops line a street running through a small town in upstate New York. Credit: iStock.com/DebraMillet

In the United States, 2020 will be remembered not just for a global pandemic but also for a series of back-to-back and record-breaking disasters that affected much of the country, including many rural communities. As tempting as it may be to consider the severe losses and impacts from these events in isolation—the challenges of a year that will not soon be forgotten—the trend of rising losses from natural hazards has been visible for many years. From 2015 to 2020, according to NOAA, the United States was hit annually by at least 10 weather- and climate-related disasters that each caused more than $1 billion in damages [*Smith*, 2020].

Even more troubling than this overall trend of increasing disaster losses are the inequitable outcomes that follow disasters, such as the displacement of renters, disparate impacts on persons of color, lower levels of assistance for tribal communities, and the exacerbation of food insecurity among those who were already vulnerable. Such inequities have been glaringly obvious and clearly documented, for example, in 2017 in Puerto Rico following Hurricane Maria and in California in the wake of destructive wildfires, when impacts were far worse for the poor. Similarly negative effects of the COVID-19 pandemic, on both physical and economic well-being, have resoundingly affected persons of color, tribal nations, and rural communities at disproportionately high rates.

Even more troubling than the overall trend of increasing disaster losses are the inequitable outcomes that follow disasters.

Historically, recovery efforts following disasters like floods or fires perpetuate injustice, imposing greater burdens on some fam-

ilies than on others and increasing the vulnerability of those who were already most at risk, such as undocumented persons, renters, and those living below the poverty line. Evidence of the systemic injustices and historical trends that have shaped risk landscapes in the United States can be seen clearly in many rural communities, where shrinking economies, public health crises, and extractive corporate practices have reduced the ability of local governments to deliver even basic services, much less prepare for or respond to disasters [*Jerolleman*, 2020].

Two Views of Rural Resilience

Both the media and researchers have paid a great deal of attention to climate change adaptation challenges faced by urban communities, but much less has been written or studied about rural communities and their unique challenges and, in some cases, advantages. One reason for this lack of coverage may be a general lack of visibility of rural areas, with many urban and suburban residents having little awareness of rural communities, even when they are nearby. Yet as of the 2010 census, roughly 19% of the U.S. population, or about 60 million people, still lived in areas considered rural, a rather large group to overlook.

The limited social science research into disaster vulnerability that has focused specifically on rural areas has presented two very different and conflicting perspectives of these communities' resilience [*Jerolleman*, 2020]. In the first, rural communities are often portrayed as being particularly at risk and less able to act to reduce their vulnerability, adapt to climate change, and recover from disasters. This perspective stems from clear indications that resources are very scarce at the local level and that decades of underinvestment have left many communities failing to provide basic public safety services [*Doherty*, 2004]. These shortages contrast with urban areas, which often have more staff, greater ability to access rainy day funds, and budgets that are typically both larger on a per capita basis and better able to support infrastructure demands because of the economy of scale.

Rural communities also often lack zoning or building codes and struggle to enforce codes that are in place, thereby missing out on opportunities to reduce disaster risk. A report recently released by the Federal Emergency Management Agency found that jurisdictions with modern building codes could collectively avoid at least $32 billion in losses over a 20-year period, whereas communities without modern codes would instead experience greater losses [*Federal Emergency Management Agency*, 2020]. Similarly, smaller communities with less experience navigating federal disaster assistance processes often struggle to understand the particularities of the regulations, including when and how to appeal agency decisions and seek additional funds. Furthermore, they often have challenges meeting the administrative requirements for applying for and receiving assistance because of the use of less sophisticated accounting systems and record keeping, as well as with paying costs incurred while awaiting reimbursements [*Jerolleman*, 2020].

The second perspective is that rural communities exhibit greater levels of self-reliance and are inherently more adaptive because of strong social capital, a coherent sense of identity, and long-standing relationships based on reciprocity among community members [*LaLone*, 2012]. This perspective reflects perceptions about strengths inherent in close-knit communities with long histories of adapting to environmental changes. But it does not account for the struggles being keenly felt across much of rural America or the disparate outcomes seen among such communities. Although some rural communities continue to thrive, others face massive losses of population and jobs.

One study of rural resilience identified regional variations in resilience and speculated about a correlation between resilience and extents of economic disparity along racial lines [*Cutter et al.*, 2016]. In other words, although some rural communities exhibit strong social capital and bonds that promote resilience, long histories of inequity inhibit resilience in others, particularly across the South. Research has also indicated that rural communities that are geographically closer to state capitals or urban centers are more readily able to gain advantages through regional partnerships and to access resources for emergency management [*Jerolleman*, 2020].

Although some rural communities exhibit strong social capital and bonds that promote resilience, long histories of inequity inhibit resilience in others.

Rural Adaptation with an Eye on Equity

The two portrayals above each capture elements of the experiences and realities of rural America, and both point to the unique circumstances these communities face. National and state-level strategies for reducing risk from natural hazards, including tools and resources provided to rural communities, as well as disaster preparedness and recovery efforts, must all account for these unique traits and challenges. This accounting should consider local resource constraints while also identifying ways to build upon the strengths of rural communities. Failing to follow these steps may result in continuation of policies that do not address the needs of, but instead further perpetuate inequities in, rural communities, likely resulting in successful adaptation for some but not others.

Approaches that can help increase the resilience of rural communities include the following:

- Building peer networks among communities to facilitate sharing of resources and

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Many good resources are available that can support efforts to increase rural resilience and reduce inequity following disasters. Among them are the following:

- The American Flood Coalition's Flood Funding Finder
- The National Association for the Advancement of Colored People's tool kit "In the Eye of the Storm: A People's Guide to Transforming Crisis and Advancing Equity in the Disaster Continuum"
- The Federal Emergency Management Agency's (FEMA) guide "Engaging Faith-Based and Community Organizations"
- FEMA's "Guide to Expanding Mitigation: Making the Connection to Equity"
- FEMA's "Building Cultures of Preparedness"
- The Center for American Progress's recommendations in "The Path to Rural Resilience in America"
- The Rural Resiliency Vision and Toolkit

information, such as successful strategies for navigating programs and policies that are not well designed to meet local needs. Peers may share information about successful appeals processes or about exemptions granted by agencies in other events, for example. Such dialogue can broaden the knowledge base and tools that are available and relevant for rural communities planning for or coping with disasters.

- Creating strategies that build upon existing social capital in designing preparedness and recovery efforts. For example, disaster risk reduction efforts that account for a shared vision of the community and shared commitments to retain connections valued by the community, as well as efforts that use tools such as storytelling, have been very successful [*Freitag et al.*, 2020].
- Modifying disaster recovery processes to account for differences among communities, such as differing levels of access to credit among municipalities.
- Revisiting and revising cost-benefit assessment methodologies that privilege risk reduction efforts in more populated areas with higher-value infrastructure.
- Modifying federal grant reimbursement strategies and cost-sharing requirements for hazard mitigation and disaster recovery efforts that currently overburden rural communities.

Beyond those recommendations, policymakers, climate adaptation specialists, and emergency managers must also intentionally apply an equity and justice lens to address systemic injustices. This process requires tracking unjust outcomes resulting from existing and new disaster policies and programs to determine which are failing to meet basic needs or are unevenly distributing resources.

Additional principles vital in promoting just recovery following disasters include the following [*Jerolleman*, 2019]:

- All community members must be able to exercise their agency in support of their personal well-being. This principle cannot be met if anyone is excluded from the benefits of public policies, such as when policies are irrelevant for rural residents or when all options provided by a policy are not understood by recipients and made available in a timely and accessible manner.
- Only equality is inherently defensible, whereas any unequal treatment of different groups must be justified. Bureaucratic processes that result in drastically different outcomes for rural residents, renters, or other disaster-affected individuals or communities fail this standard.
- Just recovery must harness the capacity of communities to transform and adapt while also honoring local histories of resilience. Holistic disaster risk reduction requires acknowledging and addressing existing inequalities in risk distribution and histories of disinvestment in rural areas.
- Access to resources and programs must be equal for everyone. This equality implies the full participation of smaller communities, on equal footing with larger and more populous areas, in state-level decisionmaking that determines resource allocation, disaster recovery plans, and future risk reduction.

The COVID-19 crisis is projected to result in drastic cuts to local and state government budgets. These cuts will only exacerbate challenges already faced by many underresourced rural communities at the same time that long-term impacts from the pandemic and the accompanying economic crisis are likely to increase the vulnerability of their residents.

Considering the ongoing trend of rising disaster losses and the ways in which such losses are consistently borne disproportionately by vulnerable populations, we simply cannot continue to ignore the needs of rural communities and the nearly 20% of the American population that lives within them. We have an opportunity to rethink climate adaptation and disaster preparedness and recovery to be more inclusive of all communities and to break the cycle of inequitable impacts after each and every disaster.

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ASSESSING SOCIAL EQUITY *in* DISASTERS

Natural hazard impacts and resources allocated for risk reduction and disaster recovery are often inequitably distributed. New research is developing and applying methods to measure these inequities.

by ERIC TATE *and* CHRISTOPHER EMRICH

Disasters stemming from hazards like floods, wildfires, and disease often garner attention because of their extreme conditions and heavy societal impacts. Although the nature of the damage may vary, major disasters are alike in that socially vulnerable populations often experience the worst repercussions. For example, we saw this following Hurricanes Katrina and Harvey, each of which generated widespread physical damage and outsized impacts to low-income and minority survivors.

Social vulnerability researchers seek to understand the impediments and capacities of people and communities to prepare for, respond to, and recover from extreme natural hazards. A major tool in this work is social vulnerability modeling, the use of which is expanding in large part because of growing awareness of the social equity implications of disasters.

New Orleans, La., houses surrounded by debris and floodwater from Hurricane Katrina in 2005. Credit: Jerry Grayson/Helifilms Australia PTY Ltd/Getty Images

This modeling applies knowledge garnered from disaster case studies describing how chronic marginalization translates to disproportionate adverse outcomes to identify the most vulnerable population groups. Such populations often include those living in poverty, the very old and young, minoritized ethnic and racial groups, renters, and recent immigrants [*National Academies of Sciences, Engineering, and Medicine*, 2019]. Social vulnerability modelers select demographic variables representing these groups and combine them to construct spatial indicators and indexes that enable comparisons of social vulnerability across places.

Mapping Social Vulnerability

> The use of social vulnerability modeling is expanding in large part because of growing awareness of the social equity implications of disasters.

Figure 1a is a typical map of social vulnerability across the United States at the census tract level based on the Social Vulnerability Index (SoVI) algorithm of *Cutter et al.* [2003]. Spatial representation of the index depicts high social vulnerability regionally in the Southwest, upper Great Plains, eastern Oklahoma, southern Texas, and southern Appalachia, among other places. With such a map, users can focus attention on select places and identify population characteristics associated with elevated vulnerabilities.

Many current indexes in the United States and abroad are direct or conceptual offshoots of SoVI, which has been widely replicated [e.g., *de Loyola Hummell et al.*, 2016]. The U.S. Centers for Disease Control and Prevention (CDC) has also developed a commonly used social vulnerability index intended to help local officials identify communities that may need support before, during, and after disasters.

The first modeling and mapping efforts, starting around the mid-2000s, largely focused on describing spatial distributions of social vulnerability at varying geographic scales. Over time, research in this area came to emphasize spatial comparisons between social vulnerability and physical hazards [*Wood et al.*, 2010], modeling population dynamics following disasters [*Myers et al.*, 2008], and quantifying the robustness of social vulnerability measures [*Tate*, 2012].

More recent work is beginning to dissolve barriers between social vulnerability and environmental justice scholarship [*Chakraborty et al.*, 2019], which has traditionally focused on root causes of exposure to pollution hazards. Another prominent new research direction involves deeper interrogation of social vulnerability drivers in specific hazard contexts and disaster phases (e.g., before, during, after). Such work has revealed that interactions among drivers are important, but existing case studies are ill suited to guiding development of new indicators [*Rufat et al.*, 2015].

Advances in geostatistical analyses have enabled researchers to characterize interactions more accurately among social vulnerability and hazard outcomes. Figure 1b depicts social vulnerability and annualized per capita hazard losses for U.S. counties from 2010 to 2019, facilitating visualization of the spatial coincidence of pre-event susceptibilities and hazard impacts. Places ranked high in both dimensions may be priority locations for management interventions. Further, such analysis provides invaluable comparisons between places as well as information summarizing state and regional conditions.

In Figure 2, we take the analysis of interactions a step further, dividing counties into two categories: those

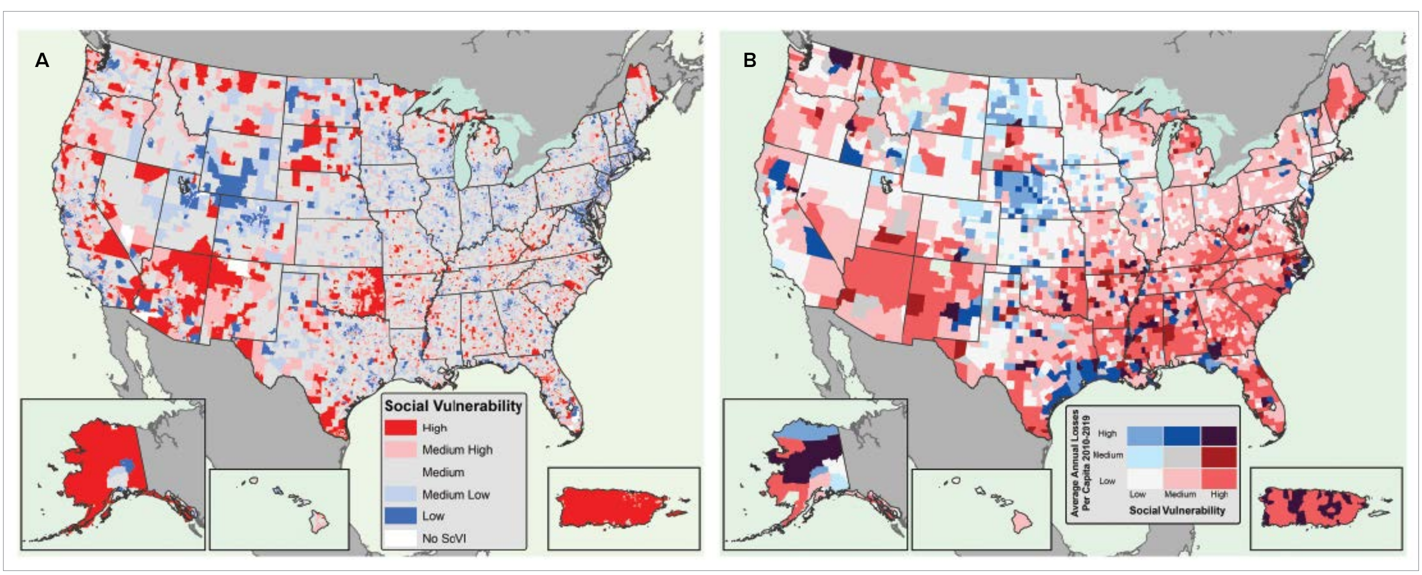

Fig. 1. (a) Social vulnerability across the United States at the census tract scale is mapped here following the Social Vulnerability Index (SoVI). Red and pink hues indicate high social vulnerability. (b) This bivariate map depicts social vulnerability (blue hues) and annualized per capita hazard losses (pink hues) for U.S. counties from 2010 to 2019.

experiencing annual per capita losses above or below the national average from 2010 to 2019. The differences among individual race, ethnicity, and poverty variables between the two county groups are small. But expressing race together with poverty (poverty attenuated by race) produces quite different results: Counties with high hazard losses have higher percentages of both impoverished Black populations and impoverished white populations than counties with low hazard losses. These county differences are most pronounced for impoverished Black populations.

Our current work focuses on social vulnerability to floods using geostatistical modeling and mapping. The research directions are twofold. The first is to develop hazard-specific indicators of social vulnerability to aid in mitigation planning [*Tate et al.*, 2021]. Because natural hazards differ in their innate characteristics (e.g., rate of onset, spatial extent), causal processes (e.g., urbanization, meteorology), and programmatic responses by government, manifestations of social vulnerability vary across hazards.

The second is to assess the degree to which socially vulnerable populations benefit from the leading disaster recovery programs [*Emrich et al.*, 2020], such as the Federal Emergency Management Agency's (FEMA) Individual Assistance program and the U.S. Department of Housing and Urban Development's Community Development Block Grant (CDBG) Disaster Recovery program. Both research directions posit social vulnerability indicators as potential measures of social equity.

Social Vulnerability as a Measure of Equity

Given their focus on social marginalization and economic barriers, social vulnerability indicators are attracting growing scientific interest as measures of inequity resulting from disasters. Indeed, social vulnerability and inequity are related concepts. Social vulnerability research explores the differential susceptibilities and capacities of disaster-affected populations, whereas social equity analyses tend to focus on population disparities in the allocation of resources for hazard mitigation and disaster recovery. Interventions with an equity focus emphasize full and equal resource access for all people with unmet disaster needs.

Yet newer studies of inequity in disaster programs have documented troubling disparities in income, race, and home ownership among those who participate in flood buyout programs, are eligible for postdisaster loans, receive short-term recovery assistance [*Drakes et al.*, 2021], and have access to mental health services. For example, a recent analysis of federal flood buyouts found racial privilege to be infused at multiple program stages and geographic scales, resulting in resources that disproportionately benefit whiter and more urban counties and neighborhoods [*Elliott et al.*, 2020].

Investments in disaster risk reduction are largely prioritized on the basis of hazard modeling, historical impacts, and economic risk. Social equity, meanwhile, has been far less integrated into the considerations of public agencies for hazard and disaster management.

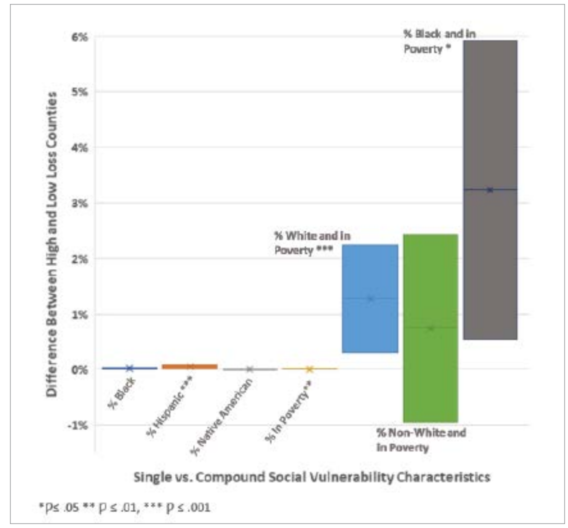

Fig. 2. Differences in population percentages between counties experiencing annual per capita losses above or below the national average from 2010 to 2019 for individual and compound social vulnerability indicators (race and poverty).

But this situation may be beginning to shift. Following the adage of "what gets measured gets managed," social equity metrics are increasingly being inserted into disaster management.

At the national level, FEMA has developed options to increase the affordability of flood insurance [*Federal Emergency Management Agency*, 2018]. At the subnational scale, Puerto Rico has integrated social vulnerability into its CDBG Mitigation Action Plan, expanding its considerations of risk beyond only economic factors. At the local level, Harris County, Texas, has begun using social vulnerability indicators alongside traditional measures of flood risk to introduce equity into the prioritization of flood mitigation projects [*Harris County Flood Control District*, 2019].

Unfortunately, many existing measures of disaster equity fall short. They may be unidimensional, using single indicators such as income in places where underlying vulnerability processes suggest that a multidimensional measure like racialized poverty (Figure 2) would be more valid. And criteria presumed to be objective and neutral for determining resource allocation, such as economic loss and cost-benefit ratios, prioritize asset value over social equity. For example, following the 2008 flooding in Cedar Rapids, Iowa, cost-benefit criteria supported new flood protections for the city's central business district on the east side of the Cedar River but not for vulnerable populations and workforce housing on the west side.

Furthermore, many equity measures are aspatial or ahistorical, even though the roots of marginalization may lie in systemic and spatially explicit processes that originated long ago like redlining and urban renewal. More research is thus needed to understand which measures are most suitable for which social equity analyses.

Challenges for Disaster Equity Analysis

Across studies that quantify, map, and analyze social vulnerability to natural hazards, modelers have faced recurrent measurement challenges, many of which also apply in measuring disaster equity (Table 1). The first is clearly establishing the purpose of an equity analysis by defining characteristics such as the end user and

Table 1. Major challenges in measuring social equity

ISSUE	CHALLENGE FOR EQUITY MEASURES	MEASUREMENT CONSIDERATIONS
Analysis purpose	Aligning analysis with end use and users	Audience, intended intervention, hazard type, disaster phase
Equity mode	Assessing distributional versus procedural equity and individual versus compounding inequity	Measuring process equity, identifying appropriate compound metrics
Validity	Reflecting underlying processes of inequity	Connecting variable selection with vulnerability processes, choosing absolute versus relative impact measures
Scale	Linking spatial and temporal scales with underlying vulnerability processes	Data availability and acquisition costs
Robustness	Determining statistical reliability	Measurement error and sensitivity analysis

intended use, the type of hazard, and the disaster stage (i.e., mitigation, response, or recovery). Analyses using generalized indicators like the CDC Social Vulnerability Index may be appropriate for identifying broad areas of concern, whereas more detailed analyses are ideal for high-stakes decisions about budget allocations and project prioritization.

Selecting the relevant modes of equity for analysis is crucial. Is the primary interest to quantify disparities in the distribution of hazard impacts or procedural disparities in accessing resources? Is the focus on individual populations or on combinations of population characteristics? As social inequities often accrue to low-income households, analysts should consider assessing economic losses in both absolute and proportional terms.

A major challenge is to develop statistically robust measures and best practices for assessing disaster equity that strengthen the foundation for policy interventions.

Creating valid measures of equity requires not only statistical expertise but also a fundamental understanding of the underlying processes of social marginalization. This facilitates selection of optimal proxy indicators and their geographic scales. However, practical considerations like data availability and cost can lead to indicator selection that diverges from conceptual bases. For example, for disaster assistance received by households, an equity analysis should ideally be conducted at the household scale. Unfortunately, data describing some dimensions of inequity, like race, are rarely collected by disaster agencies, necessitating analysis using census data at larger geographic scales.

The final major challenge is to develop statistically robust measures and best practices for assessing disaster equity that strengthen the foundation for policy interventions. Doing so may require expanding current approaches to include sensitivity analyses to assess how choices of parameters (e.g., input variables, geographic scale) in building social vulnerability indicators affect the statistical stability of resulting measures, and how these measures correlate with observed disaster impacts like dislocation, assistance eligibility, and recovery time.

The stakes for improving our understanding of relationships among hazards, vulnerability, and social equity are high, as climate disasters from flooding, drought, tropical cyclones, and wildfire have been increasing in their frequency and destruction. By definition, *sustainable* solutions that empower communities to resist, recover from, and adapt to these threats must be not only economically viable and environmentally sound but also socially equitable. Well-designed measures of disaster equity are an important tool for quantifying disaster disparities, which is the first step toward dismantling them.

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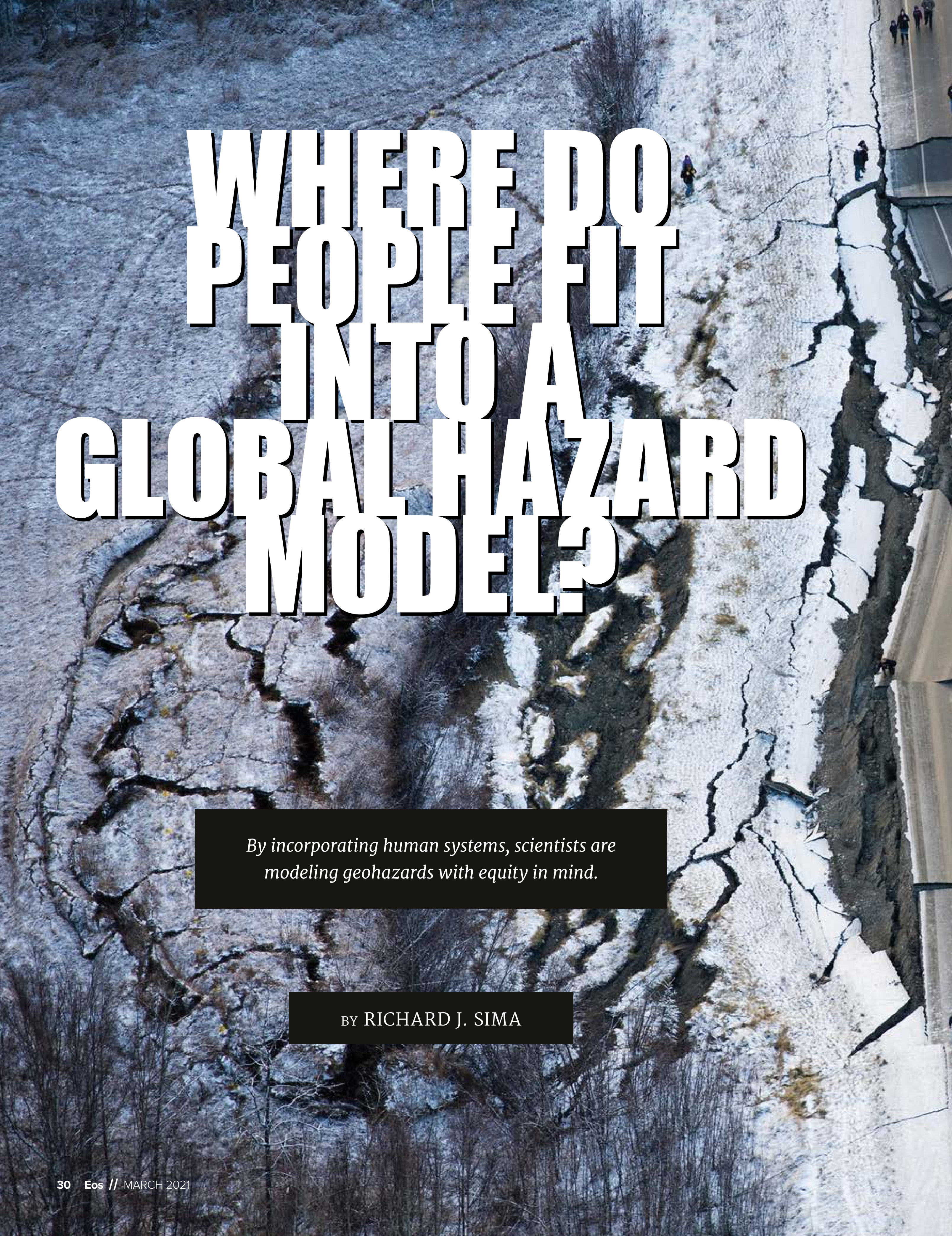


WHERE DO PEOPLE FIT INTO A GLOBAL HAZARD MODEL?

By incorporating human systems, scientists are modeling geohazards with equity in mind.

BY RICHARD J. SIMA

This road south of Wasilla, Alaska, and the ground around it were shattered by back-to-back magnitude 7 and 5.7 earthquakes on 30 November 2018. Credit: Marc Lester/ Anchorage Daily News/Associated Press

Earth still shook during 2020's pandemic lockdowns.

Vitor Silva recalled a request to his organization from Italy's Civil Protection Department in March.

"One of the directors said, 'Look, there's this global pandemic. It's going to affect all the countries. There are a lot of uncertainties when it comes to earthquakes, but we know for sure that within the span of a year, we're going to have earthquakes and, yes, some of them are going to be destructive.... So should we try to get ahead and identify the places where there's a higher likelihood of earthquakes happening and there is also a good likelihood [of having] a huge impact in terms of COVID?'"

Scientists make connections between COVID-19 and earthquake vulnerability in the aftermath of an earthquake disaster, when displaced people are often relocated to shelters where proximity to other victims puts them at increased risk of diseases.

This query was not completely out of the blue for Silva, who is the risk coordinator at the Global Earthquake Model Foundation (GEM), a scientific organization based in Pavia, Italy, whose mission is to calculate and communicate earthquake risk. In August, Silva published a study modeling the potential impact seismic events may have on coronavirus infection rates. He also created a map of high risk areas by combining models on seismic activity and the potential economic costs of building damage with data from Johns Hopkins University on the number of COVID-19 cases in each country. Since the map was created in April,"We had destructive earthquakes in Mexico, in Greece, and in Croatia," Silva said. When Silva went back to check the map, he found that all those places had been highlighted as having the highest risk for earthquakes and COVID-19.

"It's almost like I want to say, 'I told you so,'" Silva said. "I think this map can help national authorities by looking at different locations where they should basically change their plans."

The pandemic has changed how governments deal with natural disaster preparedness. In a nonpandemic year, countries may have plans for relief following earthquakes, floods, and landsides, but "these plans involve putting a lot of people in closed spaces," Silva said, including "temporary shelters, which a lot of times are tents or hotels or gymnasiums. That's probably no longer acceptable now in the time of COVID."

Silva's research highlights the importance of understanding the intersection of geoscience modeling with human systems such as settlement patterns, economics, and migration; knowing where and who the people affected are is essential for effectively modeling natural hazards.

GEM is a model for how scientists are modeling the processes of Earth with human equity in mind.

"When we start running the risk analysis, what we're doing is simulating many, many, many earthquakes, basically millions of possible earthquakes that might happen in the future."

Collaboration and Openness in Modeling Natural Hazards

Since its founding in 2009, GEM has been carrying out a broad spectrum of activities that support its "mandate of making the world more resilient to earthquakes," said Marco Pagani, the hazard team coordinator at GEM.

To carry out its mission, GEM's modeling work is divided among three core teams. Pagani's Hazard Team assesses the geophysical phenomena of seismic hazard: Where, how much, and how frequently is the ground going to shake? The Risk Team then figures out what is going to be exposed and vulnerable to that earthquake hazard: Where are the buildings and people, and how vulnerable are they to harm? The Social Vulnerability Team assesses the resiliency of communities to earthquakes on the basis of socioeconomic indicators such as the Human Development Index, the number of hospital beds per capita, and crime levels.

In 2019 GEM published its first comprehensive map of seismic hazard around the globe, which is the result of an extensive collaborative effort to combine the probabilistic seismic hazard models of many different nations and regions of the world. The organization has continued to update the components of the map since its release.

"It's a dynamic compilation that is able to receive the new models that are made available," said Pagani.

This flexibility is due to OpenQuake, an open-source hazard and risk calculation tool developed by GEM. The OpenQuake engine is the computer code backbone of GEM. OpenQuake code undergoes extensive testing, Pagani said, which makes the tool ready to accept contributions from a large modeling community around the world.

"OpenQuake is almost a bit of a Frankenstein because we had to consider functionalities of a lot of tools that exist out there," Silva said. The engine is being refined and improved on the basis of community feedback and specific project needs. "We have several projects with several governments, bilateral collaborations, international partnerships, and we had to improve this tool in order to meet the requirements."

In a way, the researchers said, OpenQuake embodies GEM's ethos of collaboration, openness, and transparency.

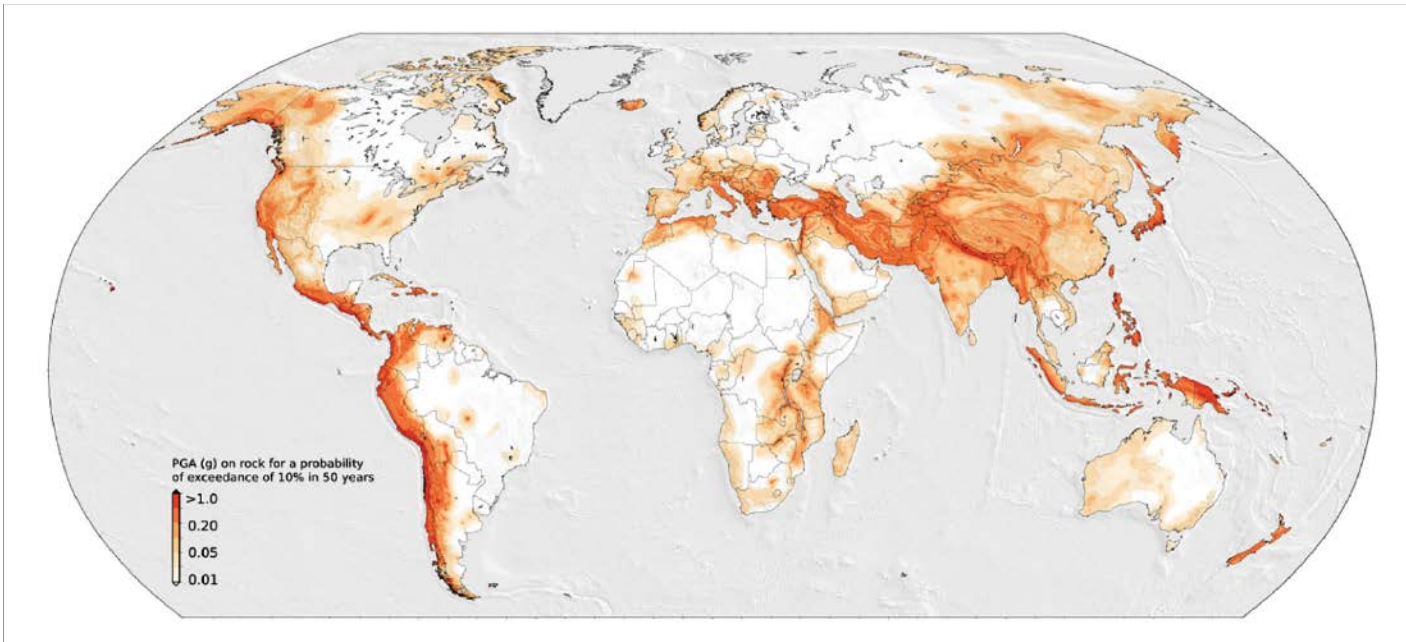
"First of all, it's free: You can go right now to download it and use it. Second, it's completely transparent, so you can actually open it and see the methodology, see line by line to really understand what it's doing. And third, you can provide your own routines, your own algorithms, you can write your own pieces of code and provide this to the community," Silva said.

Modeling Risk on the Ground

Silva's Risk Team develops exposure models to figure out what human systems are going to be exposed to the earthquake hazard. That is, what are "the buildings, the bridges, the people, basically everything that is exposed to the seismic hazards?" said Silva.

However, the amount and the quality of data available about buildings vary from country to country, which in turn affects what kinds of information can be input into the risk model.

"If I start with countries like the United States, like Canada, like New Zealand, like Australia, like Switzerland, these countries actually have extremely complete catalogs of the built environment," Silva said. "So there's information about where the build-



Global seismic hazard model representing ground acceleration. Credit: Vitor Silva, Global Earthquake Model

ings are, the main construction materials, how many stories, construction age. All this information, it's available in public databases."

Other nations, many in underdeveloped regions of central Asia and Africa, are less likely to have exact information about the buildings within their borders. But they may have socioeconomic data—population locations, economic composition—that can be used to estimate how many buildings can be expected in different locations. "There is more uncertainty, but it is still possible for us to come up with something," Silva said.

Finally, there are countries for which almost no building information is available. "In this case, we've been using a lot of new technologies, like remote sensing satellite data or OpenStreetMap data," Silva said. Using satellite data, it is possible to understand where urbanized areas are, for example, and estimate the average sizes or heights of buildings in those areas. "It's obviously much more time-consuming but something that is necessary to do for some countries."

All told, the global exposure model includes 1.3 billion residential, 90.9 million commercial, and 35.5 million industrial buildings. The estimated price tag of all that real estate? About $203.6 trillion.

"We need to make sure that all of this information is captured on the exposure model," said Silva. "When we start running the risk analysis, what we're doing is simulating many, many, many earthquakes, basically millions of possible earthquakes that might happen in the future."

For each simulated earthquake, GEM estimates the shaking on the ground, the damage to the buildings, and the expected losses. After considering all the different seismic events and their probabilities (an *M*9 earthquake is fortunately much rarer than smaller seismic events), the risk analyses generate the probabilities of exceeding different levels of loss. The model also takes into account the vulnerability, or fragility, of the affected buildings.

"For a lot of the countries, this is the first time that an open-sourced risk model was available for the country, which is a fundamental tool for people to start investing in disaster risk management measures," said Silva. For example, GEM provided modeling and data for northern Africa, western Africa, northeastern Europe, northeastern Asia, Mexico, and the Korean Peninsula. Recently, GEM was also added to the Nasdaq Risk Modelling service to better inform financial and insurance markets.

Limits of Census Data

Before GEM came along, there were other global seismic risk models, such as the Global Seismic Hazard Assessment Program, which was developed in 1992. These older models tended to have vulnerability and exposure estimates that were not tailored to specific counties. "Our knowledge, technology, and tools evolved a lot since the '90s," Silva said.

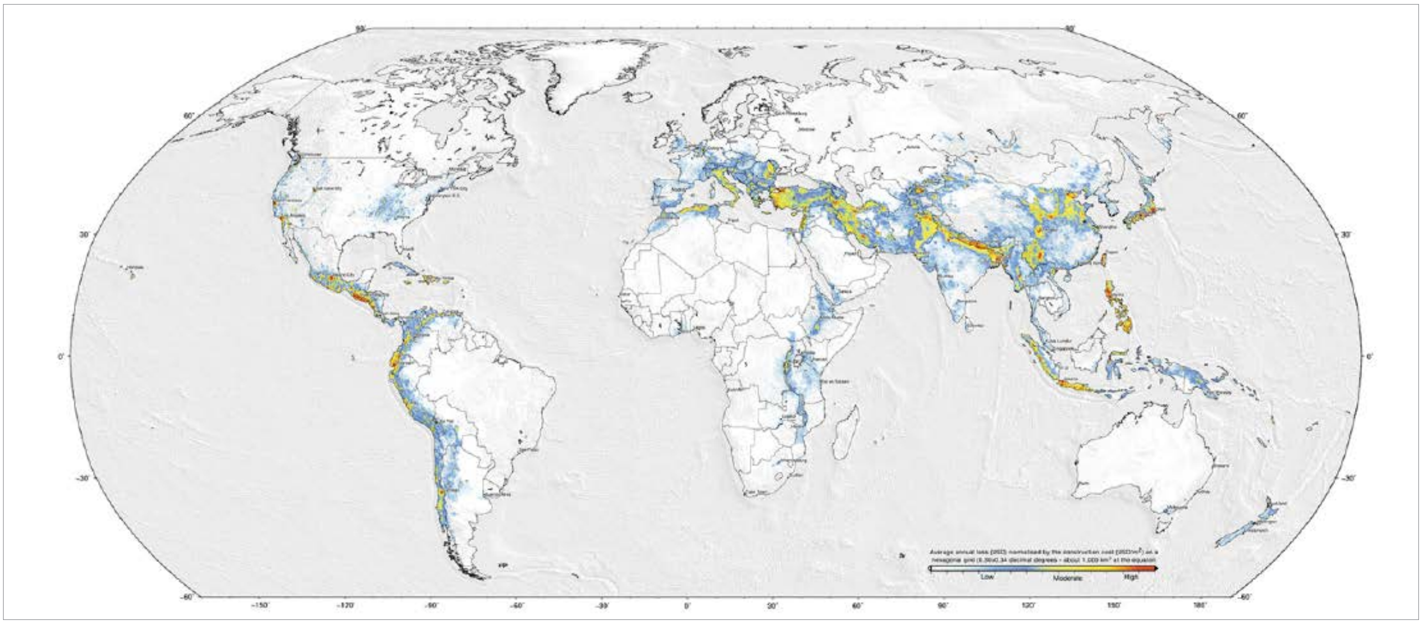
Despite the importance of building and demographics data for risk modeling, it is still difficult to get some crucial information directly through most national censuses, meaning that this information often needs to be gathered elsewhere.

Having information on how buildings were constructed is crucial for modeling their vulnerability to natural hazards, said Nicky Hastings, the risk assessment project lead at Natural Resources Canada. "Wood has a lot of flexibility, for example. Some of the more rigid structures of the unreinforced masonry obviously don't flex as well when you have ground shaking.... And that's very different from, say, a flooding event. A wooden structure does not do well in flooding events, but a concrete structure will." Hastings and her team are developing seismic risk as well as coastal flooding models for Canada.

Unfortunately, the Canadian census, which is taken every 4 years, does not include information on the construction of buildings. "So it's information that we have been developing over the years and using some different methodologies to collect and then to develop algorithms to understand," Hastings said.

Before the advent of Google Maps, Hastings's collaborators at the University of British Columbia collected information about different types of construction by simply walking by and observing buildings from the outside. Now they are able to use photographs on Google Street View, which "was a really big advance to help us get the construction types and get a sense of what that looks like," Hastings said.

Hastings and her colleagues are in the process of developing an open-source flood risk modeling tool. "I think there's still a



Global seismic exposure model representing average annual losses of building replacement cost. Credit: Vitor Silva, Global Earthquake Model

long way to go. It's not the same level as the seismic model is," she said.

Hastings's team has created consistent and standardized maps that could be applied to natural hazards modeling. In the United States, a new database allows property owners to get an easy-to-understand indicator of the potential for flooding now and over the next several decades.

"My dream is to do the same kind of thing with the various geohazards," Hastings said.

The date buildings were constructed also matters, because building codes have changed over time, said Helen Crowley, a seismic risk consultant at the nonprofit Eucentre. Crowley and Eucentre recently helped develop and publish the exposure model for European seismic risk in close collaboration with GEM and as part of the European Commission's Horizon 2020 Seismology and Earthquake Engineering Research Infrastructure Alliance for Europe project.

Understanding when seismic design codes were introduced and enforced helps develop the model to better reflect the vulnerability of different buildings. For example, after the 1908 Messina earthquake, Italian design codes recommended that buildings be able to withstand more lateral force. However, those building codes were initially required only in areas where earthquakes had occurred but not across the whole of Italy. But as more earthquakes occurred over the following century, more municipalities required seismic design codes. Records of adoption and implementation of seismic design codes varied within a single country, therefore, as well as across international borders.

"The problem is that every country has slightly different data in their census," Crowley said. "So one country will tell us the number of dwellings, they might tell us about the number of buildings, there might be information on the height of those buildings, the age of those buildings, and in some cases, the external material."

Hastings and Crowley both also want to investigate the movement of people when assessing seismic vulnerability because the distribution of the population changes throughout the day as people commute from home to work and back.

"We want to use that data in the future and look at how people move during the week, during seasons," Crowley said. "Obviously, where people are in the summer, where they are in the winter is very different. So these are all things that we want to add to the model in the kitchen, but by now we don't have that in our model." These types of data also are not captured in a census.

"The [U.S.] Census itself has hardly anything," said Bruce Spencer, a statistician at Northwestern University who has participated in evaluations of population estimates by the Census Bureau. "I think the first step is for the natural hazards community to think about what information they would like to get their hands on for which geographic areas, and then to try to see where we can find that data."

The American Community Survey, an ongoing demographic survey program from the U.S. Census Bureau, may include more detailed information than the annual decadal census, with a higher temporal resolution of updated results each year. Researchers outside the government, however, typically won't have access to that level of detail to protect the confidentiality of the data, Spencer said. It is possible to collaborate with the Census Bureau and have them run a more in-depth analysis through the Research Data Center, which allows qualified researchers access to more detailed data than the bureau would normally release.

"It is a way to, for statistical purposes, use very fine grained data," Spencer said. "So if you wanted to look at disparities in risk profiles, going down to a very fine grained geographic level, you could do that. You wouldn't be able to report it for an individual city block, but you could report it for large aggregates of city blocks to say these populations are at higher risk."

In addition, the U.S. Department of Housing and Urban Development sponsors the American Housing Survey, which is conducted every other year and provides up-to-date information about the physical condition of homes and neighborhoods, the cost of maintaining homes, and who lives in those homes.

"I think that this is a very ripe area for people working in natural hazards and people more familiar with social science and social surveys to collaborate on," Spencer said.

Social Vulnerability

In addition to modeling how natural hazards pose risk to buildings, scientists are beginning to assess the differing social vulnerabilities populations have in recovering from natural hazards.

GEM has a small team dedicated to assessing social vulnerability following a seismic event. In calculating the direct costs of seismic events, "we're talking about dollars, and we're talking about people," Silva said.

By collecting many socioeconomic indicators at the global scale, such as the Human Development Index (used by United Nations Development Programme and including factors such as per capita income, life expectancy, and education levels), crime levels, and the number of hospital beds per capita, GEM was able to create a composite indicator for social vulnerability that could help prioritize resources to assist areas with both high direct risk of seismic events and social vulnerability.

Mojtaba Sadegh, a civil engineering professor at Boise State University whose research has focused on flooding, drought, and wildfires, uses income as a proxy for vulnerability because wealth can buffer against some of the effects of these hazards. For example, the smoke caused by wildfires kills more people than the fires themselves, but those with the economic means can afford HEPA filters and advanced air conditioning to mitigate their effect, Sadegh said. These human factors need to be incorporated into hazard modeling.

Although social vulnerability indexes can help map where the most and least vulnerable areas are, practitioners find it hard to use this information, said Jackie Yip, a coastal risk scientist at Natural Resources Canada. "If you don't know why a neighborhood is vulnerable, then how do you reduce their vulnerability?"

Vulnerability is made up of many dimensions, and the factors driving it are dependent on both the context and the type of hazard, Yip said.

Armed with Canadian census data, Yip is using machine learning computer algorithms to find patterns in what drives social vulnerability across different neighborhoods based on indicators related to housing conditions, financial agency, social integration, and individual autonomy.

This neighborhood archetype model shows different neighborhood profiles of why a place may be more likely to be vulnerable; one neighborhood may have a higher concentration of elderly and low-income residents, whereas another may have more residents who don't speak English or French as their first language, which suggests different challenges for recovering from a natural disaster.

"We are not trying to label these neighborhoods as these things," Yip said. "We are just giving a high-level view of what is driving social vulnerability" to help practitioners prioritize where to focus.

Integrating social sciences is "something that is often lacking in the hazard field because it is usually done by engineers, but they don't have the training toward the social side," Yip said.

So far, this work is still very top-down and has been implemented only in British Columbia, but Yip plans to expand the approach to all of Canada after establishing whether the model reflects reality on the ground by working with people living in these neighborhoods.

"We can't have just a data-driven [model] about people without talking to people," Yip said.

Sadegh agreed. "The purpose of any model is to improve human livelihood and to save human lives. At the end of the day, this is the ultimate goal."

> **"We're trying to model the world, right? And we're trying to model the future of the world."**

Hazards and Models Crossing Borders

To achieve better equity in natural hazard modeling, the process needs to be collaborative and global, experts say. Natural hazards don't stop at borders even if how they are modeled differs on either side.

When GEM works on building a model for a certain region, for example, it makes sure to first get in touch with the community leaders, Pagani said. "We try to engage them into those projects because we recognize the importance of working with local experts."

Hastings and the Geological Survey of Canada are working with the Semiahmoo, a First Nation community on the Pacific coast, as part of an effort to understand the priorities and values different communities have surrounding coastal flooding. They are developing a guideline to set best practices, "because a model is a model, but you don't know if it actually works until you test it in the community," Hastings said.

The Semiahmoo collaboration "brings together some of the Indigenous Knowledge with the scientific knowledge, and it came about from that more holistic perspective," she said.

The Semiahmoo were a community before there was a Canada-U.S. border. When the border was put in place, the community was severed, Hastings said. This separation was evident when, at a conference, a counselor stood up and mentioned the large differences in coastal flooding models produced by the U.S. side and those produced by the Canadian side. Now Hastings and her team are working with their U.S. counterparts at NOAA and the University of Washington to clarify what these differences are.

"The model inputs are different, the modeling is different, and of course, there are political differences," Hastings said.

"And you don't realize it because you tend to work within your country until you start working together," she added. "The really cool thing about this specific study is we're really starting to learn, cross border, some of those big differences...and you may not be able to resolve them all right away, but at least you can bring some clarity in terms of what the differences are."

Silva agreed. "The development of these models involved literally hundreds of people around the world. We did dozens of meetings and workshops," he said. "We went to all these different places, we held meetings with people, we showed the results, we ran the calculations with them," Silva said. "We identified a lot of mistakes, a lot of errors in the model by working with the local people. I also think that something that maybe differentiates [the GEM model] a little bit is the fact that it was a community effort."

"We're trying to model the world, right?" said Hastings. "We're trying to model the future of the world."

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Natural Hazards Have Unnatural Impacts—*What More Can Science Do?*

AS DISADVANTAGED COMMUNITIES SUFFER DISPROPORTIONATELY FROM NATURAL HAZARDS, SCIENTISTS, POLICYMAKERS, AND EMERGENCY MANAGERS EXPLORE WHY POLICIES ARE FAILING—AND WHAT CAN BE DONE ABOUT IT.

by **KORENA DI ROMA HOWLEY**

A sign hangs on a tree in front of a house damaged by Hurricane Michael in Panama City, Fla., in 2018. Credit: REUTERS/Terray Sylvester

By any measures, 2020 was an extraordinarily challenging year—and natural hazards played no small role. In North America alone, a record number of Atlantic storms caused nearly 400 deaths and billions of dollars in damage, wildfires burned nearly 9 million acres in 13 U.S. states, and multiple earthquakes of significant magnitude damaged or destroyed thousands of homes and buildings in Puerto Rico. Worldwide, COVID-19 caused more than 1.5 million deaths, and storm and monsoon flooding affected millions across Asia.

As climate change leads to a growing number of severe weather events and as natural hazards increasingly affect communities on multiple fronts, both scientists and policymakers have a challenging task: ensuring that solutions and recommendations arising from scientific research are communicated effectively and applied equitably.

The latter challenge is particularly critical. According to the World Bank, economically disadvantaged populations make up a disproportionate number of those affected by natural hazards worldwide. Such populations live in low-lying areas prone to flooding, in older buildings less able to withstand earthquakes or to seal out hazardous air, and in the path of increasingly frequent and powerful storms.

These communities "are first more exposed, and then more vulnerable," said Alan Kwok, disaster resilience director for Northern California Grantmakers, a regional funding organization. In the United States, residents of low-income communities are simultaneously less able to move away from hazardous places and less able—due to time and resource constraints—to prepare for or respond to disasters. "Financial resources are a huge predictor of whether you're prepared and can recover," Kwok said.

"THE FACT THAT WE CAN LOOK BACK AT RESEARCH THAT'S 70 YEARS OLD AND SAY 'THIS STILL HASN'T BEEN INTEGRATED INTO POLICY' IS A SUGGESTION THAT THERE'S BEEN A FAILURE THERE."

When Hurricane Katrina struck the Gulf Coast in 2005, nearly a million of the region's residents were impoverished, and communities of color in New Orleans were particularly vulnerable. In Puerto Rico, more than 40% of the population was living in poverty when Hurricane Maria caused widespread devastation in 2017. In both instances, failures in government response were met with criticism and deeply underscored disparities in access to resources and the ability to recover and rebuild.

"The approach we were taking was extremely ineffective and also extremely unjust," said Samantha Montano, an assistant professor of emergency management at Massachusetts Maritime Academy. Montano received firsthand experience with recovery efforts in New Orleans while working with nonprofits in the aftermaths of Katrina and the Deepwater Horizon oil spill. "What I saw when I looked around was that all of these needs were going unmet, especially in communities of color throughout the city."

Kwok notes that when speaking about the increased need for hazard mitigation and response in vulnerable communities, it's important to recognize the difference between an equality approach and an equity approach. An equality approach distributes aid, for example, regardless of background, while an equity approach takes individual circumstances into consideration. "If we're looking at equity, we know that [certain] communities, because of decades and decades of disinvestment, are coming into natural hazard events much more vulnerable.… If we're going to support these communities in their response and recovery, more investment is needed to ensure that they get back on their feet."

Connecting the Science

As with nearly all issues related to natural hazards, the challenge of increasing community preparedness and building resilience begins with science. Sophisticated earthquake early-warning systems, increasingly accurate storm forecasting, and innovative flood risk and flood mitigation projects provide communities with the tools they need to respond to impending hazard events, and infrastructure design and engineering improvements help to reduce the damage suffered during and after hazards.

Yet even as the science exists to forecast hazards and protect against the damage they inflict, the most vulnerable communities continue to feel the brunt of each event. The disconnect, said Montano, lies at the intersection of science and policy.

"We're very clear in our research about who is vulnerable in our communities, why they're vulnerable, and what we need to do to make them less vulnerable," she said. "The fact that we can look back at research that's 70 years old and say 'this still hasn't been integrated into policy' is a suggestion that there's been a failure there."

Montano said that for scientists to address these issues, it's important not only to center more vulnerable populations in their research but also to ensure that their results are being driven home to policymakers. "There are a lot of disaster researchers, emergency management researchers, who understand that the work that they're doing could bring immense value to policy and practice, but there are significant barriers for those two worlds to really be bridged," she said.

Among those barriers for scientists, according to seismologist Lucy Jones, are knowledge transfer and communication challenges, lack of direct collaboration, and an internal culture that fails to reward involvement in policy discussions. Jones is the founder of the Dr. Lucy

Jones Center for Science and Society, which advocates using science to develop community resilience. While with the U.S. Geological Survey (USGS), she spent a year partnering with the Los Angeles mayor's office on seismic policies.

"Our job [as scientists] is to say, 'Here's what the problem is,' and not how to solve it," she said. "But if you present a problem without a solution, you disincentivize action."

Jones said it's important for physical scientists to collaborate with social scientists to better connect with the human side of research. "There's a lot of information in the social sciences that helps you do a better job," she said, emphasizing that physical scientists must also learn how to apply the results of social science research. "[It's] an acknowledgment that logical reasoning is not the only factor that goes into people's decisionmaking."

It's also important to understand the nuances of different locations and communities and their individual needs, according to Gina Tonn, a senior water resources engineer with the Delaware Department of Natural Resources and Environmental Control. According to Tonn, research conducted on a broad national or geographic scale doesn't necessarily apply at the local level, where practitioners may be thinking more about how individual homeowners or members of a small community are managing risk. And even at the community level, requirements vary. "The mitigation strategy is going to be really different for a wealthier coastal community versus a coastal community with fewer resources," she noted.

One way to better understand what individual communities need is to involve their members in the development of ideas from the very beginning, said Tim Brown, a research professor in the atmospheric sciences division of the Nevada-based Desert Research Institute and director of the Western Regional Climate Center. "It allows us to understand their need, how they're seeing the result as it evolves," he said. "Working together, we can try and achieve a common outcome."

According to Brown, it helps to have a broad and expanded network and to develop rapport and trust with communities, in part by serving on committees and attending meetings. "We're constantly hearing about what's going on on the ground and thinking, 'How can we connect that with what we know about science?'"

Scientists should, above all, be proactive. At AGU, the Hazards Equity Working Group brings together natural hazards scientists who want their research to have meaningful applications and aims to provide them with the tools they need to work with an equity lens. Among their recommendations: Make demographic and census data available with research, and think about risk management communication and how factors such as local messaging can influence behavior.

In addition, AGU's Thriving Earth Exchange connects scientists with communities that have identified challenges (many of which are related to natural hazards) that they would like to address with scientific input. This community science outlook works to place community needs at the forefront of the process of defining the types of questions that are asked and approaches that are pursued to inform resilience-building efforts.

A Seat at the Table

For scientists, practitioners, and policymakers to codevelop and implement ideas—and for those ideas to effectively address inequities in the system—they must first find a way to speak to one another.

"Oftentimes miscommunication isn't intentional; it's just that we're all speaking different languages," said Natasha Malmin, a doctoral candidate in the Joint Public Policy Program at Georgia State University and the Georgia Institute of Technology.

"IF YOU PRESENT A PROBLEM WITHOUT A SOLUTION, YOU DISINCENTIVIZE ACTION."

Malmin spent 7 years as a health scientist at the Centers for Disease Control and Prevention, where she focused on climate change research and disaster preparedness and response. Today she's a fellow of the William Averette Anderson Fund, which seeks to increase representation in mitigation-related research fields by supporting people of color who are pursuing hazards and disaster studies and providing a path for their work to reach other scientists, policymakers, and community organizations.

"We have the structure, through appropriate lobbying, for scientists to have a seat at the table," Malmin said. But even when policymakers integrate science, the research may not be expansive enough to encompass both physical and social hazards. In other words, it may be missing the human factor.

"Within the world of science, we may give, literally, a seat but not necessarily a voice," Malmin said. "We may give a voice, but the language isn't there.... It goes back to, 'How are we understanding what the problem is?'"

Malmin said that as a start, community advocates should join scientists and policymakers at the table. "Advocates can help broaden the narrative and refine the problem," she said. "I wouldn't be able to articulate the cascading effects of hazards and how policies can shape and decide who's vulnerable and who's not if I didn't live in those communities."

According to Beth Butler, executive director of New Orleans–based A Community Voice, the issues faced by affected communities often begin with policies that exacerbate, or even create, vulnerabilities. When Hurricane Laura hit Lake Charles, La., in August 2020, residents of the industrial city—where the poverty rate is more than double the national rate—lost their homes and faced damage to their communities even as they coped with worsening COVID-19 rates. The city, said

Butler, already suffers from unmitigated development on land that is cheap and accessible but increasingly vulnerable to flooding. "They need to connect with the people who live there," Butler said of policymakers. "They need the representation of lower- and moderate-income people who represent groups that are actually involved in these fights.... You have to have the people involved."

Butler said that to effectively communicate issues such as climate change and its role in weather-related hazard events, it's also necessary for policymakers to understand the culture of regional communities, such as those along the Gulf Coast. These are communities, she said, that are tied to the land—to fishing, farming, and a legacy of inhabitance going back hundreds of years or, for Indigenous communities, even further. "These considerations have to be brought into the whole panoply of issues and campaigns around how to mitigate...the climate change [effects that are] wreaking havoc on these families who live in coastal communities" and other areas vulnerable to such hazards as tornadoes and flooding.

Though community advocates may increasingly find a place in the conversation, progress in collaboration between even scientists and policymakers alone can be noteworthy. Pamela Williams, executive director of the BuildStrong Coalition, emphasized the important role scientists played recently in passing legislation that directly benefits vulnerable communities. Williams was the principal architect and negotiator of the federal Disaster Recovery Reform Act, which was signed into law in 2018. The reforms incorporated, in part, lessons learned from 2017's deadly and destructive natural hazards, which included some of the costliest hurricanes seen in the United States. A key accomplishment was the allocation of 6% of annual disaster spending for predisaster mitigation, administered through a Federal Emergency Management Agency (FEMA) program called Building Resilient Infrastructure and Communities (BRIC).

"WE UNDERSTAND HOW TO RETROFIT A BRIDGE OR ELEVATE A HOUSE, BUT WE DON'T NECESSARILY KNOW HOW TO [APPROACH] SOCIAL MITIGATION OR INVESTMENTS IN HUMAN CAPITAL."

"We were able to successfully participate in that conversation and drive that policy because we brought new players to the table [who provided] significant amounts of risk data," Williams explained. "It was truly a conversation and a legislative policy discussion founded in science and data, and that's how we were able to get a bipartisan agreement.... We [showed] that investments in mitigation have [anywhere] from a $4 to $11 return on investment—and we had the professionals and data to back that up."

For Williams, one of the biggest challenges when working with scientists is translating scientific data into more generally digestible information. "One of the things that I have been most surprised about through the entire mitigation conversation is how stovepiped we all are," she said. "BuildStrong endeavors to break down those stovepipes and get everyone talking, because...a lot of things get lost in translation."

Williams said she particularly appreciates those researchers who are able to have one foot in science and one foot in policy discussions. They help tell a necessary story in a way that better demonstrates the risks being faced. "We have to show [communities] that there are very real steps, tested and grounded in science, that they can take to at least reduce that risk and to become more resilient," she said.

Derrick Hiebert is a hazard mitigation strategist with Washington State's King County Emergency Management. He believes that to get the information needed, practitioner involvement should begin as early as the design of the research idea. And the research itself must include social factors to be practical.

"What I could use from researchers is more information on what I need to do to change the vulnerability equation for a place," he said. "I need to know what the root cause is...because we understand how to retrofit a bridge or elevate a house. But we don't necessarily know how to [approach] social mitigation or investments in human capital.... [Which] investments in a community are going to have the greatest return when it comes to reducing risk and reducing disparity in the way people suffer disaster outcomes?"

Hiebert acknowledged that knowing *how* to collaborate with scientists can be a challenge, but he thinks that in some cases, such collaboration can come down to a quick phone call, to "maintaining relationships as opposed to trying to create formal engagements." His advice to researchers: "Develop relationships, get to know people, get involved in the emergency management community, and people will start listening."

Toward a More Collaborative Future

Despite the many barriers and challenges that exist, several programs currently under way prove that scientists, practitioners, and policymakers are ready to be on the same page.

Anne Wein, a USGS principal investigator based in California, analyzes data from multihazard scenarios such as ShakeOut, ARkStorm, and HayWired—large, collaborative, interdisciplinary projects with input from Earth scientists, engineers, and social scientists. In an effort to better connect with decisionmaking, Wein and other team members translate scientific data from the scenarios into information about societal consequences.

"The beauty of these scenario projects is that we are cocreating with partners and stakeholders," she said, citing as an example collaborative work with regional

> **"IN THE BIGGER-PICTURE POLICY CONVERSATION, WE ABSOLUTELY NEED TO RECOGNIZE THAT THERE ARE PEOPLE WHO REMAIN UNSEEN FOR A VARIETY OF REASONS, AND WE CAN'T FAIL TO ADDRESS THEIR NEEDS."**

economists for the HayWired project. "We are really working side by side with people."

Hiebert cites FEMA's BRIC program as one with an outlying focus on equity and collaboration. The program incentivizes, for instance, public outreach and community and agency partnerships, as well as projects that benefit socially vulnerable populations and those that account for future conditions and climate change development trends. Hiebert—who along with other emergency management professionals contributed to BRIC's development—believes such incentives are groundbreaking. With this program, he said, "We've institutionalized the idea that places that are more likely to suffer loss and recover slowly get more investment, or at least prioritized investment."

Said Williams, whose role with the BuildStrong Coalition focused initially on ensuring that BRIC would be as successful and effective as possible, "In the bigger-picture policy conversation, we absolutely need to recognize that there are people who remain unseen for a variety of reasons, and we can't fail to address their needs… and that's why we are such large advocates of systemic investments in resilience."

As part of resilience-building, Williams highlighted the need for effective messaging, beginning at the policy-planning level with creative partnerships that can help present a unified statement.

At the local level, Wein said, it's important first to listen to community members to understand what they consider their own vulnerabilities to be. "We've got all this wonderful science," she said, "but how does it resonate with the community?"

Like Brown and Malmin, Jones believes that to understand a community's needs, it's important to engage on a personal level. "Be part of your own community," she said. "I have the most impact when I'm working with people who already know me." She added that leadership at academic institutions should explore how they can support those who want to be involved in policy. "Cultural change really does have to happen," she said, and though it may not be something one advocate can accomplish, individuals can help shift the outlook and the practical policies of their institutions.

Rather than use the term science communication, which she believes implies a unilateral process, Jones talks about science activation, or empowering people to use science. She works with young scientists on how to engage with policymakers, including through interaction with both state and federal legislators. With the help of such experiences, these students may become the people who, as Williams advocated, bridge the science–policy gap and tell the stories that will lead to action.

"Fundamentally," Jones said, "until we change how the larger society, including policymakers, [is] trained to use scientific information, we aren't going to solve the problem."

Author Information

Korena Di Roma Howley (korenahowley@gmail.com), Science Writer

▶ **Read the article at bit.ly/Eos-hazard-impacts**

Tracking How Plastic Moves in the Coastal Ocean

Plastic debris floats near the ocean surface off Bali, Indonesia. Credit: iStock.com/Nuture

At least 8 million tons of plastic waste end up in the ocean annually, collecting in great swirling patches on the surface and even sinking to the deepest depths. Researchers know that most of this plastic litter originates on land, but it is less clear how it moves around in the coastal zone, where ocean waves meet the beach.

In a new study, *Alsina et al.* build on previous theoretical work considering wave-induced particle drift with an experimental setup. The team used a 16-meter-long flume with a wave-generating paddle at one end and a beach section to dissipate waves at the other. The researchers first released plastic particles between 4 and 12 millimeters wide—on par with some of the most common pieces of ocean litter—and with different densities into still water. They then generated nonbreaking waves with varying periods and steepness and tracked the 3D trajectories of the particles to find out how differences in size and density affected wave-induced transport.

In the experimental setup, most of the particles tended to move on the surface of the water or close to the bed, although the authors note that under real-world conditions, particles would likely be more distributed in the water. The team found that the relative density of the particles and their location within the water column had the largest influence on drift behavior. Particles on the surface tended to move shoreward, pushed by the action of Stokes drift. Sunken particles also moved shoreward along the seabed, transported by the wave boundary layer motion.

Further research is needed to understand the behavior of plastic particles in the surf and swash zone. But the authors note that the study provides an experimental look at physical principles driving plastic behavior in the shallow coastal zone, a critical step for future work to combat marine pollution. (*Journal of Geophysical Research: Oceans*, https://doi.org/10.1029/2020JC016294, 2020) **—Kate Wheeling,** *Science Writer*

A Census of Snowdrifts in Northern Alaska

Snowdrifts are iconic features of frigid high-latitude landscapes. They are also important natural phenomena that dictate how fresh water flows through those landscapes once snows melt in the warmer months. Despite their importance, however, snowdrifts remain understudied.

In a new study, *Parr et al.* use a combination of lidar and structure-from-motion photogrammetry to chart snowdrift formation over 126 square kilometers of Alaskan tundra between 2012 and 2018. The term drift may imply a transient, shifting nature, but the new research describes snowdrifts as rather reliable phenomena, occurring in the same locations and configurations year after year during the study period. The researchers say this is largely because the drifts are a function of underlying topography, tending to accumulate along low points in the landscape that are protected from wind, such as along river cutbanks or lake edges, in trenches and gullies, and near outcrops.

The results confirm the outsized importance that snowdrifts have on a region's hydrology. Drifts accounted for only 18% of the land area in the study region, but they contained 40% of the snow water equivalent. This disparity also highlights another finding of the study: that snowdrifts are almost always found concomitantly with scour regions—areas with lower than average snow coverage.

The scientists caution that even though the snowdrifts they observed showed remarkable consistency over the 6-year study period, they are still complex formations that depend on a host of variables subject to climate change. Rain-on-snow events, for example, which are predicted to increase in the region in the future, can cause icy crusts to form, preventing drifting entirely and dramatically altering the landscape. (*Water Resources Research*, https://doi.org/10.1029/2020WR027823, 2020) **—David Shultz,** Science Writer

Snowdrifts, like those seen here at a lake in the northern foothills of the Brooks Range in Alaska, are important drivers of ecology in the frozen tundra of Alaska. Credit: Charles Parr

Drivers of Upper Atmosphere Climate Change

Concerns about climate change often focus on Earth's lower atmosphere, where most of the weather we experience occurs. However, climate change also affects the upper atmosphere. Understanding climate trends in the upper atmosphere could aid many applications, such as planning satellite missions and interpreting their data, managing space debris, and assessing the risk of disruptive space weather.

Research by *Cnossen* provides new insights into trends and drivers of upper atmosphere climate change, highlighting the important roles of both carbon dioxide and Earth's magnetic field.

The green glow of aurorae is seen on the horizon in this photo taken from the International Space Station as it passed over Europe in March 2015. Credit: NASA Johnson Space Center, CC BY-NC 2.0 (bit.ly/ccbync2-0)

Although the lower atmosphere has been warming, the upper atmosphere—above 100 kilometers in altitude—has been cooling in recent decades. Previous research suggests that this cooling trend is driven by a combination of greenhouse gas emissions, shifts in Earth's magnetic field, and long-term variations in solar and geomagnetic activity associated with the solar cycle.

To further understand these drivers, the author used the Whole Atmosphere Community Climate Model with thermosphere and ionosphere extension (WACCM-X) to simulate changes in atmospheric temperature and density from Earth's surface to an altitude of 500 kilometers between 1950 and 2015. The analysis included careful accounting of the effects of the solar cycle—typically a major challenge in upper atmosphere research. After factoring in these effects, the simulation confirmed earlier suggestions that rising carbon dioxide levels are the main driver of long-term cooling in the portion of the upper atmosphere known as the thermosphere. However, long-term shifts in Earth's magnetic field also appear to play a significant role in thermospheric climate change toward the North and South Poles.

The analysis also addressed the ionosphere, the charged portion of the upper atmosphere. The simulation suggested that long-term changes in ionospheric density are driven by both carbon dioxide and Earth's magnetic field. Magnetic field effects on the ionosphere's climate are particularly pronounced above a region that stretches roughly from northeastern South America across the Atlantic to western Africa.

These findings could help inform future research into upper atmosphere climate change and its long-term implications. (*Journal of Geophysical Research: Space Physics*, https://doi.org/10.1029/2020JA028623, 2020) **—Sarah Stanley,** *Science Writer*

New Insights into Uncertainties About Earth's Rising Temperature

Climate models help researchers predict how much Earth's temperature will rise because of greenhouse gas emissions. However, even with the same starting parameters, different models can predict a wide range of potential warming. *Becker and Wing* provide new insights into why global warming predictions can vary so widely.

The new findings stem from the Radiative-Convective Equilibrium Model Intercomparison Project (RCEMIP). RCEMIP aims to enable comparisons among different climate and weather models by configuring them according to a simplified yet fairly accurate representation of tropical weather patterns. This mathematical simplification treats the tropics as a closed system in which radiative cooling and convective heating balance each other out.

The researchers analyzed climate sensitivity, or the amount of climate warming expected from an increase in greenhouse gas emissions, and found very different results for the 31 models included in RCEMIP. The results revealed that more than 70%–80% of the variation in climate sensitivity across models can be explained by differences in how the models simulate the influence of rising temperatures on shallow cloud cover and on how convection—which involves warm, rising air that forms thunderstorms—clumps clouds together.

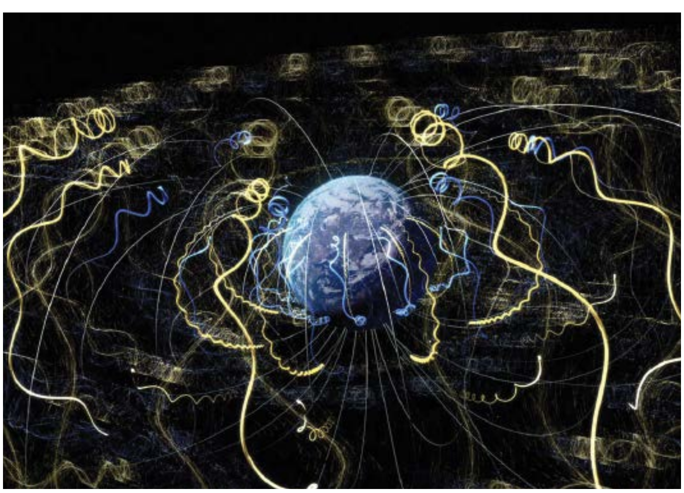
The team also found that global climate models may underestimate climate sensitivity, whereas cloud-resolving models tend to predict a greater degree of warming.

More work is needed to tease out exactly why the models produce the different warming-dependent changes in cloud cover and convection seen in the study, the researchers suggest. But they note that these findings could help researchers use radiative-convective equilibrium and other mathematical tools to reduce uncertainties in predictions of emissions-driven warming. (*Journal of Advances in Modeling Earth Systems (JAMES)*, https://doi.org/10.1029/2020MS002165, 2020) **—Sarah Stanley,** *Science Writer*

A New Approach to Characterizing Space Plasmas

In studying the behavior of plasmas, large collections of electrons and ions, physicists often consider a plasma's kinetic distribution, which depends on both the positions and the velocities of the particles. Kinetic distributions are already averaged over time intervals and over tiny regions of phase space, and further averaging yields a coarse-grained "single-fluid" description of the plasma, achieved by taking velocity moments of the entire kinetic distribution.

Zero- and first-order moments yield the plasma's fluid density and particle flux and hence the single-fluid flow velocity. Second-order moments yield thermal and kinetic energy densities, which describe the single-fluid temperature and bulk kinetic energy associated with the flow velocity.



This artist's conception illustrates the motion of charged particles in Earth's magnetosphere. The complexities of these motions can be treated more simply by using approximations in which particle distributions are decomposed into multiple independent beams. Credit: NASA Goddard Space Flight Center's Conceptual Image Lab

The satellites in NASA's Magnetospheric Multiscale Mission have recently measured kinetic particle distributions over time intervals much faster than in earlier missions. These high-resolution distributions frequently show more than one distinct velocity peak, or beam, present at the same time in the same spatial region.

Taking single-fluid moments of such multibeam distributions can yield counterintuitive results. Imagine, for example, two equal beams of particles moving in opposite directions with all particles moving at the same speed. Because their velocities cancel out when averaged, single-fluid moments can appear to contain all thermal energy and no bulk kinetic energy.

Goldman et al. addressed such misinterpretations by developing methods for taking a new kind of multibeam velocity moment of a measured distribution, in which multiple beams are identified and their single-fluid thermal moments are added together. This approach enables better understanding of how much of the system's overall fluid energy density is kinetic (i.e., associated with the beam flow velocities) and how much is thermal (i.e., associated with velocity fluctuations about the beam flow velocities). Using the new approach yields the more intuitive result that the multibeam system has all kinetic energy and no thermal energy.

The authors suggest that a multibeam approach offers clear advantages when interpreting energy transport in complex plasmas, although they note that the approach is based on assumptions, such as the number of beams into which a given distribution should be decomposed. Nevertheless, the study reinforces the need for care when interpreting complicated particle distributions. (*Journal of Geophysical Research: Space Physics,* https://doi.org/10.1029/2020JA028340, 2020) **—Morgan Rehnberg,** *Science Writer*

Atmospheric Sciences

Geospace Section Head

The Section Head serves as a member of the Division leadership team and as the Directorate's principal spokesperson in the area of geospace science research. The incumbent is responsible to the AGS Division Director for the overall planning, management and commitment of budgeted funds for the Section, which includes programs in Aeronomy, Magnetospheric Physics, Space Weather, Solar Terrestrial, and Geospace Facilities. The incumbent also serves as the Division's primary source of guidance concerning research priorities and program development in geospace sciences.

The incumbent is responsible for the day-to-day operations of the Section, including developing and executing management plans for assigned projects and evaluating and ensuring the effective us of Section staff and resources in achieving organizational goals. S/he also develops and maintains effective liaison with officials in the scientific community, other Federal, state, and local governments, and the private sector to represent Foundation and Division activities and interests and represents the Division on committees, boards, and panels in areas of expertise.

Application submission: aisern@nsf.gov

Atmosphere Section Head

The Section Head serves as a member of the Division leadership team and as the Directorate's principal spokesperson in the area of lower atmosphere research. The incumbent is responsible to the AGS Division Director for the overall planning, management and commitment of budgeted funds for the Section, which includes programs in Atmospheric Chemistry, Climate and Large-scale Dynamics, Physical and Dynamic Meteorology, and Paleoclimate. The incumbent also serves as the Division's primary source of guidance concerning research priorities and program development in atmospheric sciences.

The incumbent is responsible for the day-to-day operations of the Section, including developing and executing management plans for assigned projects and evaluating and ensuring the effective us of Section staff and resources in achieving organizational goals. S/he also develops and maintains effective liaison with officials in the scientific community, other Federal, state, and local governments, and the private sector to represent Foundation and Division activities and interests and represents the Division on committees, boards, and panels in areas of expertise.

Application submission: aisern@nsf.gov

Postdoctoral Positions: Using machine learning for bias reduction in climate models

The Atmospheric and Oceanic Sciences Program at Princeton University, in association with NOAA's Geophysical Fluid Dynamics Laboratory (GFDL), seeks four postdoctoral scientists to conduct research on improving climate models. The work is part of a larger project, M2LInES, covering eleven institutions. The overall goal is to reduce climate model biases at the air-sea/ice interface by improving subgrid physics in the ocean, sea ice and atmosphere components of existing coarse (1/4° to 1°) resolution IPCC-class climate models, and their coupling, using machine learning. The research at Princeton University/GFDL will focus on the ocean and sea-ice components with four distinct areas of research: 1) Development of machine-learned ocean model parameterizations trained on data from an ocean data-assimilation system; 2) Development of machine-learned sea-ice parameterizations trained on data from a sea-ice data-assimilation system; 3) Development of machine-learned ocean model parameterizations trained on process-study data, including large eddy simulations; 4) Implementation of existing machine-learned parameterizations in the ocean model and development and implementation of machine-learning algorithms in both the ocean and sea-ice components of the GFDL climate model. The prognostic parameterizations will be state-dependent and trained to minimize model-observation misfits with the aim of reducing inherent biases in free-running climate simulations. The research will require analysis and interpretation of model output, the management of large datasets and the application of neural nets or other machine learning techniques to those data. The postdocs will be expected to collaborate with each other and with other members of the M2LInES project.

In addition to a quantitative background, the selected candidates will ideally have one or more of the following attributes: a) a strong back-

ground in physical oceanography, sea-ice science, data-assimilation, computer science, or a closely related field, b) experience with ocean, sea-ice, climate models, or ocean/ice data-assimilation systems, and c) experience, or demonstrated interest, in machine learning.

Candidates must have a Ph.D. and preferably in Oceanography, or a closely related field. The initial appointment is for one year with the possibility of a second-year renewal subject to satisfactory performance and available funding.

Complete applications, including a cover letter, CV, publication list, research statement (no more than 2 pages incl. references), and 3 letters of recommendation should be submitted by February 28, 2021, 11:59 pm EST for full consideration. Princeton is interested in candidates who, through their research, will contribute to the diversity and excellence of the academic community.

Applicants should apply online to https://www.princeton.edu/acad-positions/position/19081. For additional information about project 1 contact Dr. Feiyu Lu (feiyu.lu@princeton.edu) for project 2 contact Dr. Mitch Bushuk (mitchell.bushuk@noaa.gov), for project 3 contact Dr. Brandon Reichl (brandon.reichl@noaa.gov), and for project 4 or general queries contact, Dr. Alistair Adcroft (aadcroft@princeton.edu).

This position is subject to Princeton University's background check policy.

Princeton University is an equal opportunity/affirmative action employer and all qualified applicants will receive consideration for employment without regard to age, race, color, religion, sex, sexual orientation, gender identity or expression, national origin, disability status, protected veteran status, or any other characteristic protected by law.

The Department of Environmental, Earth, and Atmospheric Sciences (EEAS) at the University of Massachusetts Lowell (www.uml.edu/sciences/eeas) offers several graduate research and teaching assistantships for motivated students for the Fall 2021 semester. Several positions are currently open. Information about the positions can be found on our webpage.

The University of Massachusetts Lowell (also known as UMass Lowell) is an urban public research university in Lowell, Massachusetts, with nearly 1,150 faculty members and 18,058 students. EEAS offers unique interdisciplinary study programs encompassing Geosciences, Meteorology, Hydrology, and Environmental Chemistry. EEAS offers undergraduate and graduate degrees in Environmental Sciences, with concentrations in Environmental Studies, Geosciences, and Atmospheric Sciences. Graduate School admission policies are found under https://www.uml.edu/grad/.

Job Summary: The Division of Marine Science in the School of Ocean Science and Engineering (SOSE) at The University of Southern Mississippi invites qualified applicants for a full-time, 9-month, tenure-track faculty position in Ocean Engineering at the assistant or associate professor level to begin in Fall 2021. Rank and salary will be commensurate with experience.

Primary Job Duties and Responsibilities: The successful candidate will have the opportunity to contribute to the continued development of the undergraduate Ocean Engineering program, which started in 2017, and lead its ABET accreditation. Moreover, the candidate is expected to develop a strong, externally funded research program, publish peer-reviewed literature, mentor students, participate in undergraduate instruction and develop courses in their area of study. The candidate should demonstrate the potential to contribute across disciplines and promote the continued interdisciplinary growth of the academic and research programs within the SOSE.

Additional Information: The SOSE includes two academic divisions, Marine Science and Coastal Sciences. Several R&D centers, including the Hydrographic Science Research Center, the Marine Research Center, and the Thad Cochran Marine Aquaculture Center, have research personnel that work closely with faculty in the academic divisions and research infrastructure that is available to support student training. The Division of Marine Science is based at the NASA's John C. Stennis Space Center. Stennis Space Center is a "federal" city that boasts the world's largest concentration of oceanographers and hydrographers. Marine Science faculty benefit from close working relationships with a number of on-site federal agencies, including the Naval Research Laboratory-Stennis Space Center, the Naval Oceanographic Office, the Naval Meteorology and Oceanography Command, the USGS, and NOAA including its National Data

WSL INSTITUTE FOR SNOW AND AVALANCHE RESEARCH SLF

The WSL Institute for Snow and Avalanche Research SLF is part of the Swiss Federal Institute for Forest, Snow and Landscape Research WSL and thus of the ETH Domain. WSL focuses on the sustainable use and protection of landscapes and habitats, and a responsible approach to natural hazards. WSL employs approximately 500 people, of whom 140 work at SLF in Davos.

For the new research center **"Climate Change, Extremes, and Natural Hazards in Alpine Regions – CERC"**, which is established as part of the SLF in Davos, we are seeking as of **1 July 2021** a **Research Unit Leader** (80-100%)

You will have the unique opportunity to establish and shape an interdisciplinary research unit at the SLF as part of the new research center. The research center is jointly funded by the Canton of Grisons and the WSL, with support by ETH Zurich (see **https://cerc.slf.ch**). As an internationally recognized researcher in at least one of the research areas of the new unit, you will lead the research unit with about 40 employees together with the group leaders. The coordination and promotion of research for your unit as well as the management of your own projects are part of your multifaceted and challenging responsibilities. You are committed to knowledge transfer and implementation of scientific results in practice. Furthermore, you will also be responsible for acquiring third-party funding for research projects and for liaising with authorities and organizations at national and international level. You will work closely with the head of the research center to jointly achieve the goals.

At the last years, you have pursued your scientific career with dedication, you have several years of experience in independent research, and you have an extensive track record in one or more of the following research areas: (1) permafrost; (2) alpine remote sensing, early detection and warning; (3) alpine mass movements; or (4) mountain ecosystems.

You are experienced in leading research groups and/or in managing interdisciplinary research projects. You are an integrative personality with good negotiation skills and are proficient in at least one of the national languages of Switzerland as well as in written and spoken English.

Please send your complete application to Jasmine Zollinger, Human Resources WSL/SLF, by uploading the requested documents through our webpage. Applications via email will not be considered. Dr. Christoph Hegg, Acting Director WSL, **Tel. +41 44 739 24 44**, and Prof. Dr. Jürg Schweizer, Head SLF, **Tel. +41 81 417 01 64**, will be happy to answer any questions or offer further information. The WSL strives to increase the proportion of women in its work force, which is why qualified women are particularly called upon to apply for this position.

Application link: **https://apply.refline.ch/273855/1120/12rt2acGa64TPq91MPhbbB7lY8MPbttEbh8XSiyzxQczUXF3PDol8o/apply**

Buoy Center and the National Centers for Environmental Information.

Marine Science graduate and undergraduate programs extend across traditional marine science emphasis areas in biological, physical, chemical, and geological oceanography, as well as hydrographic science and undergraduate ocean engineering. Marine Science faculty and graduate programs are based out of Stennis Space Center, where the M.S. and Ph.D. degrees in Marine Science and the M.S. degree in Hydrographic Science are delivered. The Marine Science and Ocean Engineering B.S. degree programs are delivered at the USM Gulf Coast Campus in Long Beach, MS as well as at USM's main campus in Hattiesburg, MS. The Long Beach campus is near the Port of Gulfport, which is the home port for USM's R/V Point Sur. The Port of Gulfport also features the Marine Research Center, which has a state-of-the-art fabrication lab, testing tank, and laboratory space. Gulfport will be the future site of the Roger F. Wicker Center for Ocean Enterprise and the home port of a new 199-ft UNOLS Regional Class Research Vessel (R/V Gilbert R. Mason).

Minimum Qualifications: Applicants must hold a Ph.D. in engineering or a related field and have demonstrated research experience related to the ocean. The successful candidate will be required to pass a NASA background security check to work at Stennis, and a USM employment background check.

Preferred Qualifications: Preference will be given to candidates with experience in developing academic programs and curriculums. The preferred candidate has participated in an ABET accreditation process. The candidate should have post-doctoral research experience, a demonstrated record of scholarship, service, grant development, communication, and commitment to diversity, and has experience in managing a research group. The successful candidate should have a national or international reputation for excellence in their discipline.

Special Instructions to Applicants: Applications must be submitted through the jobs.usm.edu candidate portal (https://usm.csod.com/ats/careersite/JobDetails.aspx?id=1742). For full consideration, submit 1) letter of interest, 2) curriculum vitae, 3) statement of research interests and plans, 4) statement of teaching accomplishments, plans and philosophy, 5) names and contact information of three references. All attachments must be uploaded at the time of submission. Review of applications begins 15 March 2021 and continues until the position is filled, with an anticipated start date of August 2021.

For questions regarding this position, please contact the chair of the search committee, Dr. Maarten Buijsman, by email: maarten.buijsman@usm.edu

Postdoctoral Researcher

Research will use expertise in numerical modeling and machine learning related to air quality and atmospheric chemistry at regional to urban scales. Researcher will also work with CMAQ or comparable modeling systems. The researcher will contribute to the operation, enhancement of the WSU AIRPACT air quality forecast system, and development of new machine learning models for air quality forecasting.

Application submission: https://www.wsujobs.com/

The Department of Earth and Planetary Sciences at Washington University in Saint Louis seeks a motivated postdoctoral research associate to manage a unique data visualization program within the Fossett Laboratory for Virtual Planetary Exploration. The Fossett Lab is a leader in the development of applications and outreach experiences that leverage Augmented Reality (AR) technology for education and research in Earth, planetary, and space science. The successful candidate will collaborate with the Fossett Lab Director to build and maintain AR experiences that serve the needs of Washington University instructors and scholars, and coordinate educational and outreach activities with students, faculty, administrators, and alumni.

The candidate selected for this position will also conduct research as an associate of the McDonnell Center for the Space Sciences (MCSS), and will contribute to this vibrant research community studying planetary materials, surfaces, and processes. In their application materials, the candidate should describe their research interests and list potential collaborators from among the faculty fellows of the MCSS.

Candidates must have a PhD in Earth, planetary, or space science, a record of excellent scholarship, and demonstrated interest in science communication, data visualization, and programming for AR/VR environments.

The initial appointment will be for one year and is renewable for a second year. Salary is highly competitive and research and travel funding will be available. Washington University is an equal opportunity and affirmative action employer.

To apply, please contact Professor Phil Skemer (pskemer@wustl.edu), Fossett Lab Director, with a statement of interest, CV, and contact information for three references.

EPFL

Faculty Position in History and Theory of Architecture (Digital Turn)

at the Ecole polytechnique fédérale de Lausanne (EPFL)

EPFL's School of Architecture, Civil and Environmental Engineering (ENAC) invites applications for a Faculty position in History and Theory of Architecture. The position is ordinarily open at the levels of Associate Professor or Full Professor.

The Institute of Architecture and the City (IA) is hiring a professor in the area of History and Theory of Architecture to address the systemic challenges posed by the continued climate crisis, rapid urbanization, digitalization of our society, and the threat of collapsing eco-systems. Architecture must acquire an insightful understanding of its mission as transformed and transforming disciplines with the ability and responsibility to bring up coherent, progressive and inclusive visions and solutions for our present, operating as socio-ecological catalysts within the digital and ecological transition that is vital for life on earth.

For the new Professor in History and Theory of Architecture, we intend to hire an internationally outstanding architectural historian and theoretician, with a particular research interests in the digital turn. The new professor should bring the necessary intellectual and cultural background and agenda to contextualize the historical transition of architecture, cities and the built and living environments, from the industrial age into the digital age, and provide critical and conceptual support for design across the entire institute.

The position is open to an established theoretician at Full Professor level, or renowned scholars with a publication track record at Associate Professor level. Exceptionally young rising scholars pursuing original research perspectives, can be considered at Assistant Professor (Tenure-Track) level. The appointee should have an outstanding record of pedagogic experience in architectural history and theory, a proven capacity and interest for theorizing the digital turn, and a leading and innovative research agenda.

The Institute of Architecture and the City at ENAC EPFL is an internationally leading institution in architecture, urban /territorial design and home of one of the three university level architecture schools in Switzerland. With its main campus located in Lausanne and its developing antennae in neighbouring cantons in Switzerland, EPFL is a growing and well-funded institution fostering excellence and diversity. It is well equipped with experimental and computational infrastructure, and offers a fertile environment for research collaboration between different disciplines. The EPFL environment is multilingual and multicultural, with English serving as a common interface. EPFL offers internationally competitive start-up resources, salaries, and benefits.

The following documents are requested in PDF format: cover letter including a statement of motivation, curriculum vitae, publications list, concise statements of research and teaching interests (3-5 pages) as well as the names and addresses, including emails, of at least five references (who may be contacted at a later stage). Applications should be uploaded to the EPFL recruitment web site:

https://facultyrecruiting.epfl.ch/position/28737540

Formal evaluation of the applications will begin on **March 1, 2021** and the search will continue until the position is filled.

Further enquiries should be made to the Chair of the Search Committee:
Prof. Jeffrey Huang
Chair of the Search Committee
e-mail: HTArchitecture@epfl.ch

For additional information on EPFL, please consult: www.epfl.ch or enac.epfl.ch

EPFL is an equal opportunity employer and a family friendly university, committed to increasing the diversity of its faculty, and strongly encourages women to apply.

EPFL

Tenure Track Faculty Position Environmental Resource Biorecovery

at the Ecole polytechnique fédérale de Lausanne (EPFL)

The EPFL School of Architecture, Civil and Environmental Engineering (ENAC) invites applications for a tenure track Assistant Professor of Environmental Resource Biorecovery, located within the Institute of Environmental Engineering (Institut d'ingénierie de l'environnement, IIE).

Biological wastes generated from wastewater treatment, industry or agriculture are a largely untapped source for production of value-added products or energy. Their recovery utilizes biological and chemical processes that provide alternative sources for chemical feedstocks for the production of different products (e.g., plastics or other polymers, high-value chemicals, protein for animal feed, enzymes). For instance, nutrients, cellulose, volatile fatty acids, extracellular polymeric substances or proteins can be recovered from wastewater and activated sludge. Similarly, many opportunities exist for alternative energy products, e.g., bioethanol, biobutanol, biogas, biohydrogen or bioelectricity. Resource biorecovery thus supports sustainability goals by reinjecting products into the circular economy.

We welcome applications from experimentalists whose research interests include wastewater, and who employ a range of investigative tools. In particular, candidates using multi-omics approaches combined with a systems biology component are encouraged to apply. Within EPFL, the appointee will have excellent opportunities for interdisciplinary collaborations spanning microbiology, biochemistry, biosensing and biotechnology.

We seek an outstanding individual who will lead an internationally recognized research program that leverages the opportunities offered by EPFL. The professor will be committed to excellence in undergraduate and graduate level teaching, and will contribute to the Environmental Engineering program, which emphasizes basic and translational research as the foundation for environmental adaption and engineering design.

EPFL is a growing and well-funded institution fostering excellence and diversity. It is well equipped with experimental and computational infrastructure, and offers a fertile environment for interdisciplinary research collaboration. The EPFL environment is multilingual and multicultural, with English serving as a common interface. EPFL offers internationally competitive start-up resources, salaries and benefits. Besides its main Lausanne campus, EPFL operates antenna sites across Western Switzerland, in Fribourg, Geneva, Neuchâtel and Sion.

The following documents are requested in PDF format: cover letter including a statement of motivation, curriculum vitae, publication list, concise statements of research and teaching interests (up to 5 pages for each statement) as well as the names and addresses, including emails, of at least three references (may be contacted at a later stage).

Applications should be uploaded to the EPFL recruitment web site:

https://facultyrecruiting.epfl.ch/position/28737538

Formal evaluation of the applications will begin on **April 1, 2021**. The search will continue until the position is filled.

Further enquiries should be made to:
Prof. Tamar Kohn
Chair of the Search Committee
E-mail: searchbioresource@epfl.ch

Additional information on EPFL: www.epfl.ch/en, www.epfl.ch/schools/enac, www.epfl.ch/schools/enac/research/environmental-engineering-institute-iie, www.epfl.ch/schools/enac/education/environmental

EPFL is an equal opportunity employer and a family friendly university. It is committed to increasing the diversity of its faculty, and strongly encourages women to apply.

Director of the Earth and Mineral Sciences Energy Institute

College of Earth and Mineral Sciences
The Pennsylvania State University
University Park, PA 16802

The College of Earth and Mineral Sciences at The Pennsylvania State University, University Park, PA, seeks a collaborative and strategic leader to serve as the next Director of the Earth and Mineral Sciences (EMS) Energy Institute. The Institute is a leading research and development organization focused on energy science and engineering. Areas of interest include, but are not limited to, energy transitions, energy systems, solar energy, wind energy, geothermal energy, energy access, energy policy, batteries, biomass, hydrogen, and fossil fuels. The College seeks a distinguished scholar and educator with a strong record of leadership and service. The successful candidate will hold an earned doctorate that will lead to an appointment as a full professor in one of the five departments within the College; the scientific breadth and vision needed to foster and to lead multidisciplinary and collaborative research at the Institute; a strong record of scholarly research in an energy related area; demonstrated ability to attract human and financial resources for a successful research program; and the desire to be an enthusiastic and articulate spokesperson for Penn State's energy activities. The Director will report to the Dean of the College of Earth and Mineral Sciences and is expected to build upon the tradition of excellence already established by its internationally recognized research programs. The EMS Energy Institute is part of Penn State's Institutes of Energy and the Environment (IEE, https://iee.psu.edu), which is the umbrella organization for energy-related research at Penn State.

Review of applications will begin February 10 and will continue until the position is filled. It is expected that the successful applicant will start on July 1, 2021. To apply, candidates should upload the following application materials to the Penn State career page: a cover letter, curriculum vitae, a statement of vision for the Institute, a research vision, statement of teaching philosophy, statement describing ideas for fostering diversity, inclusion and equity within the institute and the applicant's research community, and contact information for five references. Please address all inquiries and nominations to Prof. Susan Sinnott, Chair of the Search Committee and send to Ms. Peg Yetter at may14@psu.edu.

Apply online at: **https://apptrkr.com/2113427**

The Pennsylvania State University's College of Earth and Mineral Sciences takes an active role in building talented, inclusive, and culturally competent workforce. We understand that our shared future is guided by basic principles of fairness, mutual respect, and commitment to each other. Applicants should provide evidence, either woven through their application materials or as a separate diversity statement, of a commitment to fostering diversity, equity, inclusive excellence, and belonging and of engagement which creates an inclusive environment in their classroom, department, and the University.

To review the Annual Security Report which contains information about crime statistics and other safety and security matters and policies, please go tohttps://police.psu.edu/annual-security-reports, which will also explain how to request a paper copy of the Annual Security Report.

Penn State is an equal opportunity, affirmative action employer, and is committed to providing employment opportunities to all qualified applicants without regard to race, color, religion, age, sex, sexual orientation, gender identity, national origin, disability or protected veteran status.

Dear Everyone:

Maritime archaeologist Wayne Lusardi of the Thunder Bay National Marine Sanctuary in Michigan is gliding over an otherworldly "lakescape" at the bottom of the Middle Island Sinkhole in Lake Huron.

Here, under cold temperatures (~9°C water) and dim sunlight (only ~5% of surface illumination reaches the bottom of the sinkhole, at ~25-meter depth), a dynamic mosaic of cyanobacterial (purple) and chemosynthetic (white) mats flourish in groundwater containing high sulfur and low oxygen. Extreme ecosystems such as these not only contribute to Earth's biodiversity but also may add—in ways yet unknown—to the biosphere's overall physiological potential.

Hovering over this impressionistic underwater living canvas, Wayne is getting an undisturbed overview of the waterscape below with a GoPro camera before scientific operations commence. Could similarly bizarre microbial mats be awaiting us in the waters of the extraterrestrial lakes of Titan or the oceans of Europa?

—**Phil Hartmeyer** and **Stephanie Gandulla,** Thunder Bay National Marine Sanctuary, Office of National Marine Sanctuaries, NOAA, Alpena, Mich.; and **Ian Stone, Tony Weinke,** and **Bopi Biddanda,** Robert B. Annis Water Resources Institute, Grand Valley State University, Muskegon, Mich.

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